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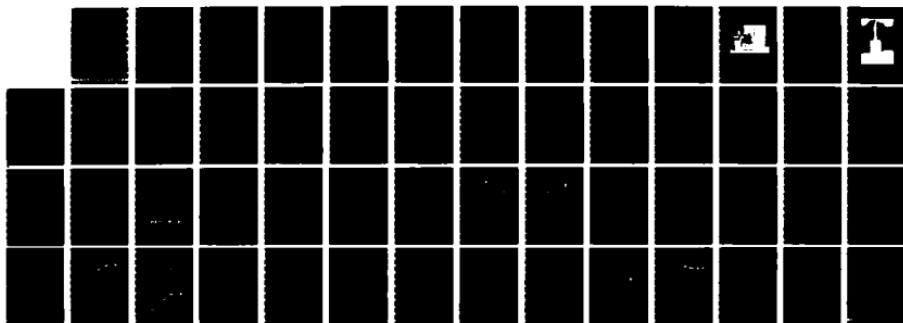
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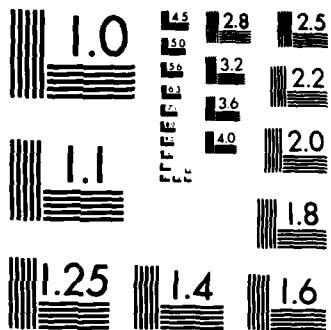
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**ACTIVITIES AND DATA FROM KIVA 1 AND 2
OPERATIONS DURING THE SUMMER OF 1985**

W. Rison

Mission Research Corporation
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Albuquerque, NM 87106

August 1986

Final Report



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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The experimental facilities Kiva 1 and 2 were used during the summer of 1985 to gather a unique data base on lightning. For the first time, simultaneous data on current, brightness, and electromagnetic fields were taken at a sampling rate of 10 ns/sample or faster. Data were only taken for two storms during the 1985 season, but the data represent a unique, high-quality sample that allows great improvement in understanding lightning. All of the three measured streamers were triggered, and the triggering methods are described in the report. Most of the report presents and explains the optical brightness, current, and electromagnetic field data.			
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1. INTRODUCTION

As part of this subtask, New Mexico Institute of Mining and Technology (New Mexico Tech), under subcontract to Mission Research Corporation, was to operate the Kiva 1 and 2 facilities during the summer of 1985 to acquire natural lightning data to improve understanding of lightning characteristics relating to lightning initiation, comparison to nuclear electromagnetic threats, and nuclear lightning. This report summarizes the experimental activities during the summer of 1985.

2. 1985 EXPERIMENTAL SETUP

The experimental setup of Kiva 1 and Kiva 2 was modified during the summer of 1985 to make the data acquisition more automated and to make electric and magnetic field and brightness measurements coincide with lightning current measurements. The main modifications are described in the following sections.

2.1 BRIGHTNESS MEASUREMENTS

Two solid state photodetectors were installed in Kiva 1 to measure the brightness of the lightning flash. These detectors were pointed above the stinger, and the outputs from them were digitized at 10 ns/sample. The setup is described fully in Kiva Memo 5.

2.2 FIBER-OPTICS LINK

A fiber-optics link was installed between Kiva 1 and Kiva 2 so that a trigger signal received in Kiva 2 would trigger the instruments in Kiva 1. The fiber-optics cable was run through the signal conduit between the Kivas. A trigger pulse from the Nanofast Peak Recorder in Kiva 2 triggers the fiber-optics transmitter. The pulse received in Kiva 1 is used to trigger the transient digitizers which record the B-dot, D-dot, and brightness signals. All instruments are triggered by the same pulse and consequently measure the same event.

2.3 SEQUENCER

A sequencer, to achieve coordinated control of instrumentation and rocket launchings, was constructed and installed in Kiva 2. The sequencer, controlled by the Hewlett Packard 9836 computer, powers up all the data acquisition instruments in Kiva 2 and sends the launch command

to fire rockets. With appropriate software for the Hewlett Packard 9836 computer, virtually all of the instrumentation in Kiva 2 is automated. All nonautomated tasks [such as turning on the video cassette recorder (VCR) to record a storm] are prompted by the computer. The computer prints out a hard copy of important information during a storm, such as the times of rocket launches, recorded footage on the analog recorder, etc. The only decision the operator has to make during a storm is when to launch a rocket.

2.4 NONCONDUCTIVE ROCKET LAUNCHING

In order to control rocket launchings from inside Kiva 2, it was necessary to send the launch command to the rockets via a nonconductive medium. A fiber-optics link was used for this purpose. A rocket control box, interfaced to the Hewlett Packard 9836 computer, transmits an optical pulse over a plastic fiber-optics cable. The pulse is received on top of the Kiva by a rocket launching box. This box is a 4-in by 5-in by 6-in metal box containing two 6-V lantern batteries, a fiber-optics receiver, and an electronic field effect transistor (FET) switch. When the fiber-optics receiver detects the light pulse from the rocket control box, it closes the FET switch. A lantern battery supplies current through the switch which ignites an electric match, launching the rocket. The only nongrounded conductive wires above the Kiva are the 0.5-m leads from the rocket launching boxes to the electric matches in the rockets. The rocket control box can control the firing of eight separate rockets.

2.5 RESISTIVE LEADER FOR TRIGGERING

A Tipsy method was developed to attempt lightning triggers with a resistive leader. A resistive leader is made of a kite string soaked in a conductive solution. The 50- or 100-m leader has a resistance of several megaohms. The leader is wound on a 1-m² plexiglass sheet (Fig. 1). The leader is positioned on the ground plane of Kiva 2 about

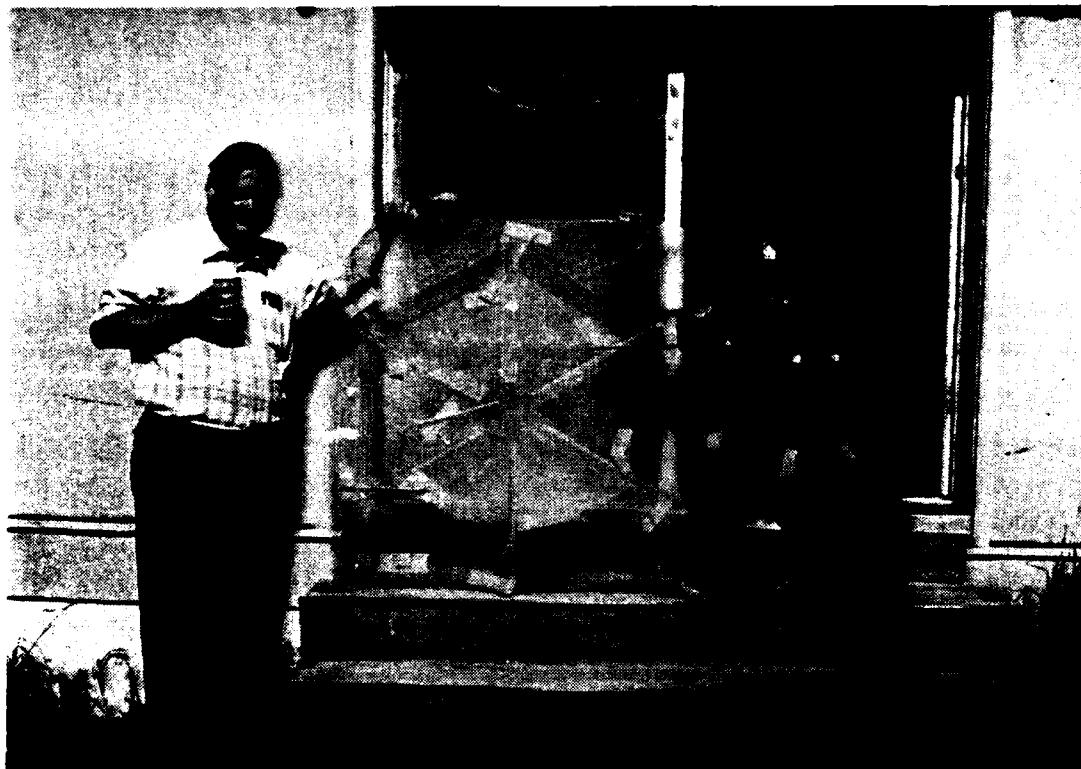


Figure 1. Resistive leader wound on plexiglass plate.

10 m north of the stinger. One end of the leader is attached to the ground plane and the other end to a wire in a bobbin carried by a GR 80 rocket (built by George Roof) as shown in Fig. 2. When the rocket is launched, the leader is unwound from the plexiglass sheet until it is fully deployed, at which point the wire from a bobbin carried by the rocket begins to deploy. The result is a 50- or 100-m length of a resistive leader between ground and the highly conductive wire carried by the rocket. If lightning is triggered using this setup, the streamer should follow the wire from the rocket to the beginning of the resistive leader at which point the streamer may find the path to the stinger preferable to the path to ground through the resistive leader. The properties of lightning triggered in this way may resemble more closely those of natural lightning than would a strike which followed a wire grounded to the stinger.

Because of the small number of storms occurring during the 1985 summer season, only one attempt was made to trigger lightning using this system. Although no lightning was triggered, a reduction was observed in the ambient electric field. This reduction was caused by dispersion of the electric charge from the ground through the resistive leader and pulling wire. The details of this are discussed in Section 4.

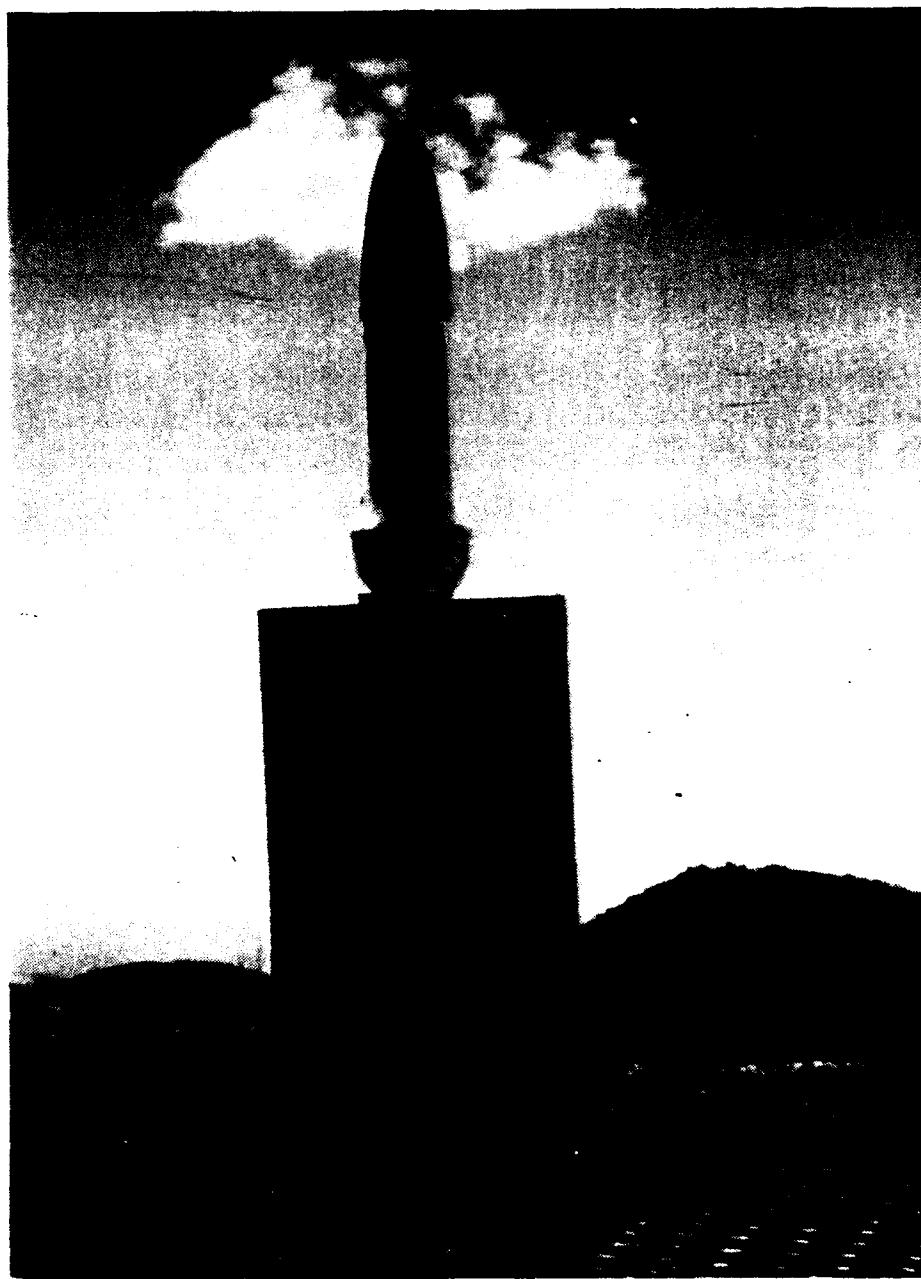


Figure 2. Rocket in launcher with wire bobbin on top.

3. EXPERIMENTAL ACTIVITY

Kiva 1 and Kiva 2 were opened on July 1, 1985, when work was begun to prepare them for the summer thunderstorm season. Both Kivas were operational by July 15, although not all of the modifications described in the previous section were fully implemented at that time. The major events occurring during the 1985 thunderstorm season are described in this section. The rockets fired during thunderstorms are described in Table 1.

The installation of the fiber-optics triggering device from Kiva 2 to Kiva 1 was completed and tested on July 20.

The first storm of the summer with fields strong enough to warrant attempting a trigger occurred on July 22. Four rockets were fired into the storm during the test (designated as D85203). In an attempt to get a free air arc to the stinger, the first rocket fired had its trailing wire grounded to the ground mesh just outside the Kiva skirt in hopes that the triggered lightning would subsequently attach to the stinger. Although this rocket triggered lightning and the recording instruments, a replay of the VCR showed that the lightning did not attach to the stinger. It was later discovered that the threshold level of the Nanofast peak recorder was set too low and that it was triggered by small currents associated with the strike, but not by the return stroke itself. The second and third rockets launched did not trigger lightning. The fourth rocket, with its wire grounded to the stinger, did trigger lightning. However, because of the low threshold of the Nanofast, the instruments were triggered on a streamer rather than a return stroke. The streamer current was too small to be recorded by the digitizers.

TABLE 1. 1985 ROCKET FIRING

DATE	TIME (MST)	LIGHTNING TRIGGERED	NOTES
D85203	13:49 13:52 14:09 14:11	Trigger Trigger	No data; Nanofast threshold set too low. Triggered at about 430 m. No data; Nanofast threshold set too low. Triggered at about 480 m.
D85209	Unknown		
D85220	Unknown		
D85222	12:09 12:12 12:19 12:27 12:32 12:39 12:43 12:49 12:52 13:13 13:18		EDS-1 Data in data section as Trigger 85220. Triggered at about 490 m. Trigger Data in data section as Trigger 85222-1. Triggered at about 320 m. Trigger Data in data section as Trigger 85222-2. Triggered at about 460 m. Trigger No data; did not trigger Nanofast. Triggered at about 400 m.
D85235	10:53 10:54		

^aHeight of trigger found by multiplying speed of rocket (about 150 m/s) times time between rocket launch and trigger as recorded on video tape.

The time delay of the fiber-optics trigger from Kiva 2 to Kiva 1 was measured on July 24. The results are shown in Table 2. A storm blew in during that afternoon. However, the instrumentation could not be brought up enough to attempt a firing. This was caused by one of the LeCroy digitizers which had a power supply problem and would not respond to the Hewlett Packard 9836 computer commands. This digitizer was returned to LeCroy for repair.

On July 28, a storm with moderate fields and little lightning blew over South Baldy. A rocket firing was attempted, but with no success.

Installation of the Lite Mikes in Kiva 1 was completed on August 7. The installation is described in Kiva Memo 5.

A late afternoon storm occurred over South Baldy on August 8. Two rockets were fired into this storm (designated as test D85220). The first rocket did not trigger lightning, but the second did. The data are presented in the next section. The data from the Kiva 1 instruments (B-dot, D-dot, and Lite Mikes) were good. However, the data from Kiva 2 did not look good. There were no data on the current viewing resistor (CVR) or the outside moebius mutual inductor, positive polarity (OMM+). The outside moebius mutual inductor, negative polarity (OMM-), and outside core current sensor (OCI) data were very noisy. These poor results occurred because the LeCroy crate could not supply the power needed to run all four digitizers and eight memory modules. The digitizers were drawing 60 A at -6 V from a supply designed for 50 A. This was the first time this problem appeared. When new, the supply could provide the extra current needed to run all four digitizers, but with age, it could not. The OCI digitizer was removed from the crate to continue operations for the 1985 season. Another Camac crate and controller are needed to record data from all four stinger outputs in the 1986 season.

TABLE 2. CABLE DELAYS

KIVA 2 Signal Lines
Stinger CVR to LeCroy: 12.5 ns
Stinger OMM+ to LeCroy: 17.5 ns
Stinger OMM- to LeCroy: 20.0 ns
Stinger OCI to LeCroy: 17.5 ns
KIVA 2 Trigger Delay
Nanofast Trigger Out to LeCroy Triggers In: 18.0 ns
KIVA 1 Signal Lines
B-Dot East to Biomation: 40 ns
B-Dot North to Biomation: 40 ns
D-Dot to Biomation: 40 ns
Lite Mike 1 to Biomation: 36 ns
Lite Mike 2 to Transiac: 36 ns
KIVA 1 Trigger Delay
Nanofast Trigger Out to KIVA 1 Triggers In: 370 ns

The best storm of the year occurred shortly after noon on August 10. Eleven rockets were fired into this storm (test D85222). Three lightning strikes were triggered. The third strike did not trigger the Nanofast (apparently its current was too small), but good data were obtained from the first two strikes. The data are presented in the next section. No data were obtained from the CVR sensor. It was later learned that an attenuator in the line from the CVR to the LeCroy digitizer was bad. There were problems (as seen from Table 3) with the Nanofast peak reader data for these triggers. The CVR and OMM- channels recorded no signal above zero. The OMM+ data appeared to be good for the first trigger, but was much too low for the second. Similar problems occurred with the Nanofast in the past. Attempts are being made to get around this problem by recording signals on more than one Nanofast channel (since several spare channels are available).

Attempts were made during the storm of D85222 to trigger lightning with a rocket pulling a resistive leader. Although the attempt was unsuccessful, the electric field record showed that the launch did deposit enough charge to reduce the electric field. This is discussed more fully in the next section.

Two rockets were fired into a storm with moderate fields on August 23 in an attempt to trigger lightning. Neither of the rockets triggered lightning.

The Kivas were kept open until September 30. There were no storms in September over the Kivas.

TABLE 3. DATA SUMMARY

		CVR		OMM		OCI	
Date	Time	Peak Reader (kA)	LeCroy (kA)	Peak Reader (GA/s)	LeCroy (GA/s)	Peak Reader (kA)	LeCroy (kA)
85220	1609:44	16.3	(a)	30	37	16.2	17
85222	1243:31	0 ^b	(a)	13 ^c	25	20.9	(d)
85222	1249:01	0 ^b	(a)	1.9 ^c	34	21.6	(d)

^aNo CVR data; burned out attenuator.

^bPeak reader read zero for CVR for these triggers.

^cPeak reader read zero for OMM- for these triggers.

^dLeCroy OCI channel disconnected due to insufficient power from crate power supply.

4. DATA PRESENTATION

Data from the three triggers to Kiva 2 are presented in Table 2 and Figs. A-1 through A-43 in the Appendix. Raw data from all sensors are shown. Data from those sensors which give field change and current change signals have been integrated and plotted as field and current data as well. Data have been plotted on several time scales to show both the rise of the signal and its long term behavior. The zero of time in the plots is the time the trigger pulse was sent from the Nanofast Peak Recorder to the transient recorders. Delays in the signal cables and trigger cables, as listed in Table 2, have been taken into account in the plots. For example, a signal measured at a sensor at $T + 1 \mu s$ after the Nanofast sent out the trigger pulse is plotted at $T + 1 \mu s$ in the plots.

The data from the triggers were recorded digitally on transient recorders. On some of the sensors, the range of the signal is on the order of 10 bits only. This is true for all the Kiva 1 sensors. A 1-bit change often represents a significant signal change, which makes interpretation of the integrals of these signals difficult. Small changes which, when integrated over long times, would cause significant contributions to the measured value did not result in a change in the digital output of the recorders. Also, a 1-bit change in a recorder due to noise is integrated as a large change in the measured quantity. In interpreting the integrated data, it is necessary to keep these points in mind, and to compare the integrated data to the raw data.

The field changes and light intensities measured by the sensors in Kiva 1 lag the currents measured by the sensors in Kiva 2 by about 100 ns. This is the time it takes for the fields to travel the 30 m from the stinger to the sensors on the roof of Kiva 1.

Electric field changes produced by the resistive leader launch and grounded wire launches during the storm of August 10, 1985, are presented in Figure A-4.

4.1 MEASUREMENT OF LIGHTNING STRIKE ON AUGUST 8, 1985

Plots of the data from the trigger on day 85220, August 8, 1985, at 1609:44 MST are shown in Figs. A-1 through A-16. As discussed in Section 3, no data were obtained from the OMM+ or CVR sensors. Raw data from these sensors are shown in Figs. A-5 and A-6. The B-dot (Fig. A-8) and D-dot (Fig. A-11) signals are similar in shape to the current change (OMM-) data (Fig. A-4). The Lite Mike data (Figs. A-13 through A-16) follow the current (Fig. A-1) well for the first 15 μ s, rising to a peak value at about T + 1 μ s, and falling until T + 15 μ s. However, as shown in Fig. A-15, the light intensity rises from T + 15 μ s and reaches a maximum at T + 150 μ s, even though the current is gradually falling during this interval. Similar behavior is observed for the other two triggers.

4.2 MEASUREMENT OF FIRST LIGHTNING STRIKE ON AUGUST 10, 1985

Plots of the data from the first trigger at 1243:31 MST on August 10, 1985 (D85222-1), are shown in Figs. A-17 through A-30.

4.3 MEASUREMENT OF SECOND LIGHTNING STRIKE ON AUGUST 10, 1985

Data from the second trigger at 1249:01 MST on August 10, 1985 (D85222-2), are presented in Figs. A-31 through A-43. The return stroke occurred at T + 1.2 μ s, rather than at T + 0 μ s as for the other triggers. The dI/dt data (Fig. A-33) indicate that current started flowing at T - 0.2 μ s. Small signals were measured by the B-dot (Fig. A-36) and D-dot (Fig. A-38) sensors at this time, although the Lite

Mikes did not pick up a signal until the return stroke at $T + 1.2 \mu s$. The current beginning at $T - 0.2 \mu s$ is most likely a streamer current, followed $1.4 \mu s$ later by a return stroke.

4.4 RESISTIVE LEADER

Eleven rockets were launched during the storm of D85222. The first rocket was launched at 1209 MST, and the last at 1318 MST. Three lightning strikes, two of which triggered the instruments, were triggered between 1243 MST and 1313 MST during this storm. The resistive leader, labelled EDS-1 (for Electrodag String 1), was launched at 1232 MST.

Figure A-44 shows the electric field recorded during the rocket launches of D85222. At each launch, the electric field is seen to decrease whether or not lightning was triggered. During the heart of the storm (from 1239 MST to 1313 MST), the two launches which did not trigger lightning reduced the electric field by about 5 kV/m in the 5 s the rocket was aloft. For the three launches which did trigger lightning, the electric field dropped by about 10 kV/m in the 1 s between rocket launch and trigger. The launches before 1239 MST caused much smaller excursions in the electric field signals from about 1 kV/m to about 3 kV/m , even though the field measured at the Kivas prior to the launches were about the same as during the heart of the storm.

After the field climbs to about 10 kV/m at the Kivas, the field measured is not representative of the field in the cloud above the Kivas. Point discharges from the ground limit the field near the surface to a value much lower than that in the cloud. Rockets climb above the space charge created by point discharge currents, and the charge deposited by a rocket will vary with the strength of the field in the cloud. The magnitude of the decrease in the field resulting from a grounded rocket launch is more indicative of the field in the cloud than is the field measured at the Kivas.

The launch of the resistive leader EDS-1 produced a field excursion of 1.5 kV/m. This is of similar magnitude as those produced by grounded rockets fired before EDS-1, but less than the 5 kV/m produced by the grounded rocket fired 7 min later. (The rocket fired 5 min before EDS-1 produced an excursion of only 1 kV/m.) There can be no certainty as to whether EDS-1 was launched when the Kiva was under the heart of the storm. If the EDS-1 launch occurred before the heart of the storm, the magnitude of the electric field excursions it produced is similar to those of grounded rockets, and the resistive leader technique will probably result in triggering lightning if fired under the right conditions.

5. RECOMMENDATIONS FOR FUTURE WORK

Several changes and additions are recommended for future work. These include:

1. Continued work on resistive leaders to find a more reliable and more easily deployed leader.
2. Continued attempts to use Primacord to trigger lightning. No Primacord triggering was attempted during 1985, but this should be pursued.
3. A new Camac crate for Kiva 2. The present Camac crate in Kiva 2 cannot supply enough current to power the four digitizers needed to measure signals from the four sensors of the stinger. Without another crate, it will be impossible to acquire a full set of data.
4. A 35-mm camera system for the oscilloscope cameras in Kiva 2. The Polaroid cameras presently used in Kiva 2 can, with trial and error, make decent scope pictures. However, adjustments, requiring much time and expensive film, would have to be made daily to ensure useful pictures during a storm. A more tolerant 35-mm system would probably result in better picture quality.
5. Reduced attenuation in B-dot and D-dot coaxial signal cables. The dynamic range of the signals measured by the B-dot and D-dot Biomations was much too low. A reduction in attenuation by a factor of about five should produce much better measurements.

6. Amplification of Lite Mike signals. There is no attenuation in the Lite Mike signal lines, yet the inputs to the digitizers are too low. An amplifier to bring these signals up to a level near the input maximums of the digitizers should give much better measurements with no loss of signal quality.

6. CONCLUSIONS

While the quantity of lightning data is not quite what is desired, the Kiva data are the best high-frequency characterization of lightning available to date. The results from the summer of 1985 are the first in which current, brightness, and electromagnetic fields have been measured on the same lightning strokes.

APPENDIX

LIGHTNING DATA RECORDS

This appendix contains plots of data of triggered lightning strikes recorded by the sensors in Kiva 1 and Kiva 2 on August 8, 1985 (D85220), and August 10, 1985 (D85222-1 and D85222-2).

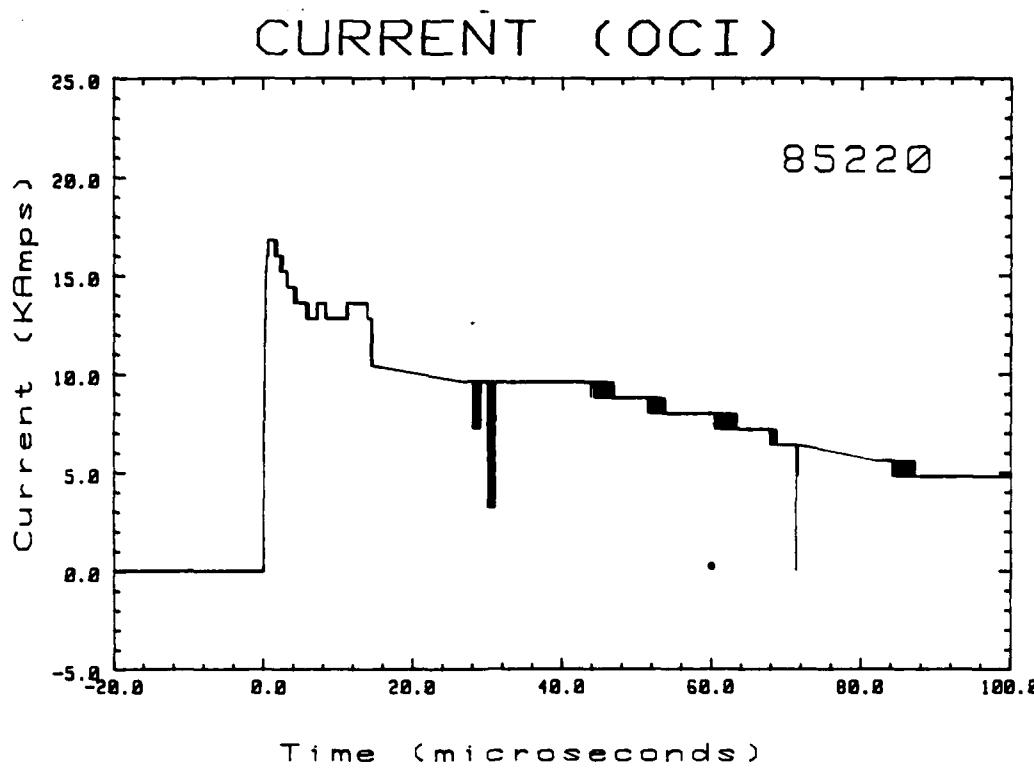


Figure A-1. Values for current measured with the OCI sensor channel for lightning triggered to KIVA 2 on 8 August 1985 (85220).

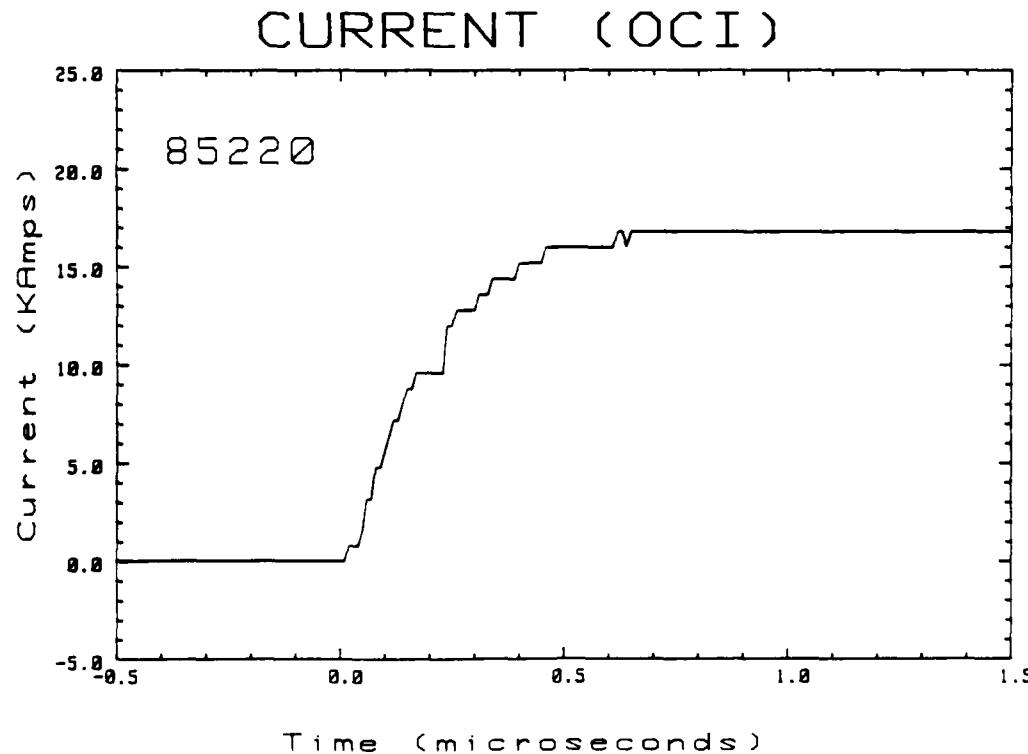


Figure A-2. Expanded view showing initial data from Figure A-1.

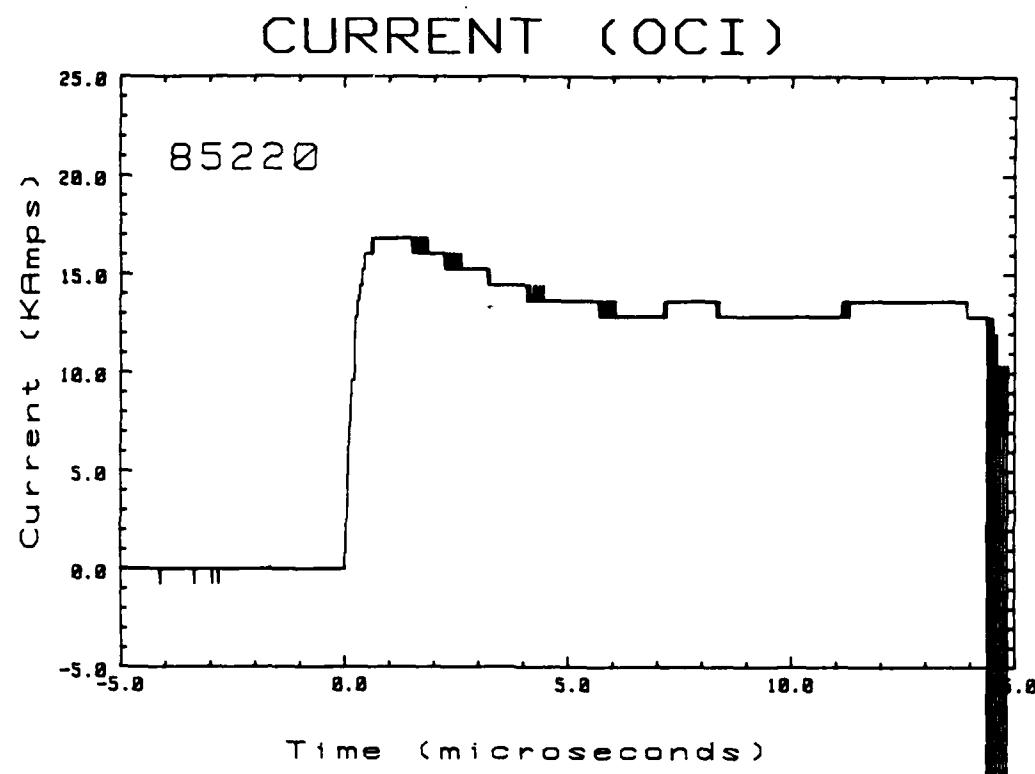


Figure A-3. View of current measured with the OCI sensor channel from $T = 5$ to $T + 15$ microseconds.

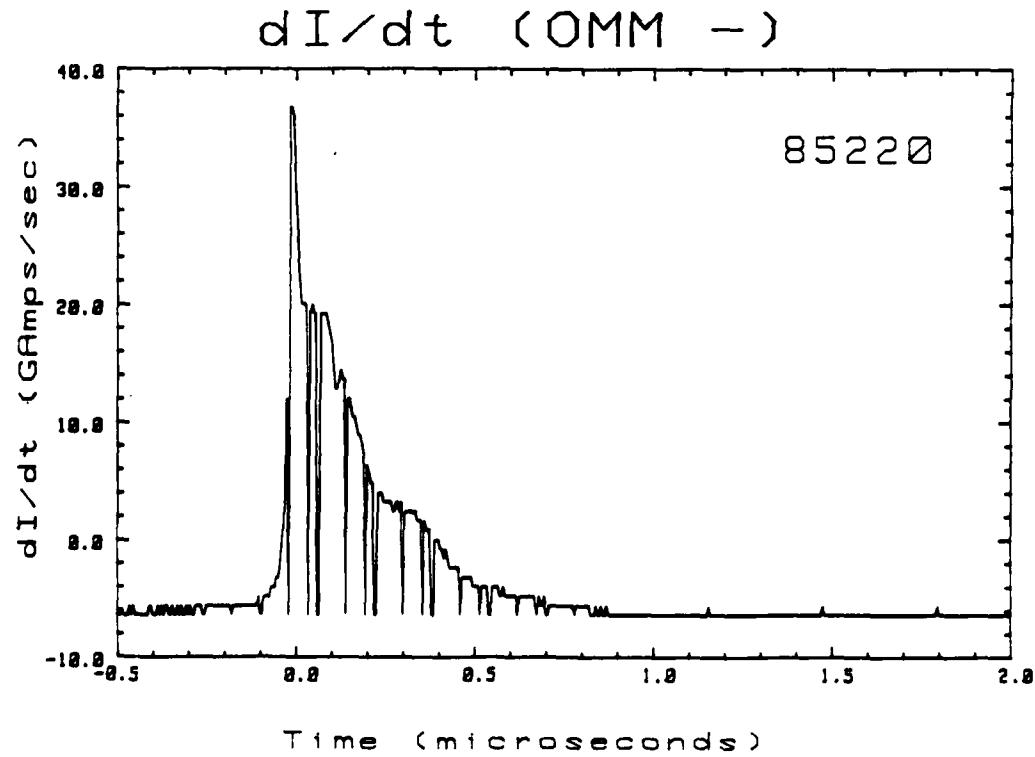


Figure A-4. Values for dI/dt measured with the OMM- sensor channel for D85220. Glitches in the data were caused by power problems in the Camac crate.

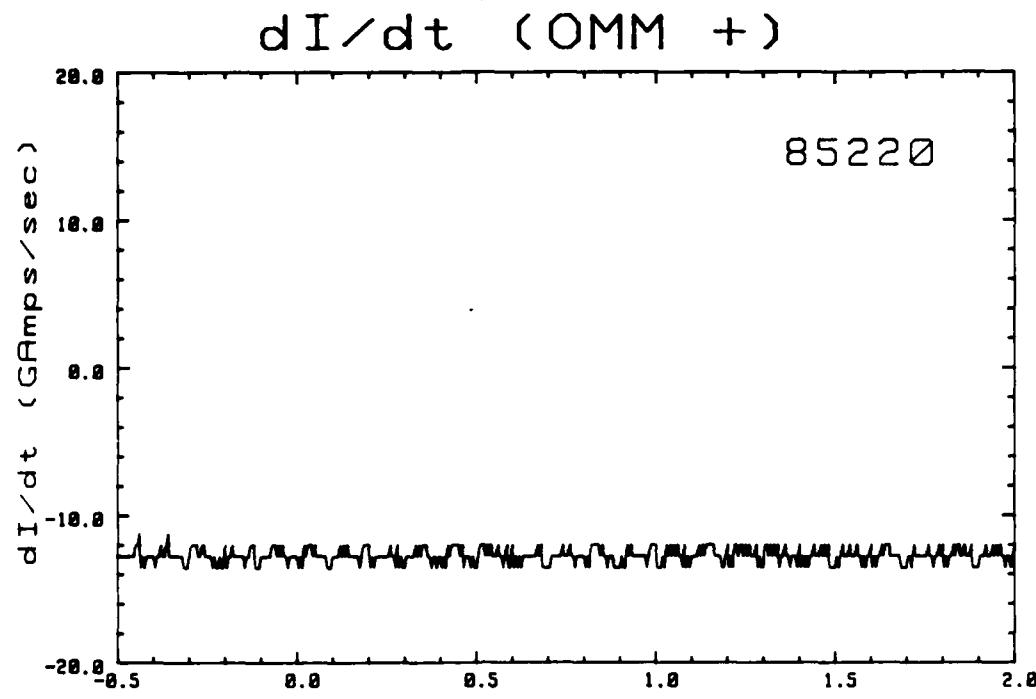


Figure A-5. Values for dI/dt measured with the OMM+ sensor channel for D85220. No data was received on this channel because of power problems in the Camac crate.

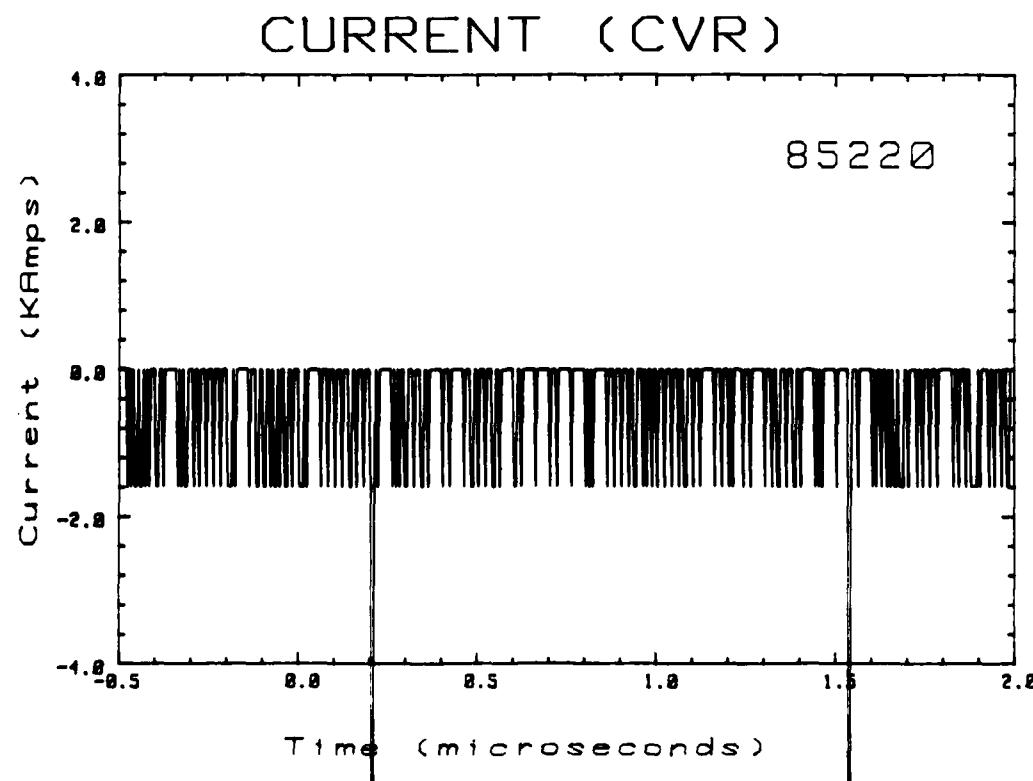


Figure A-6. Values for current measured with the CVR sensor channel for D85220. No data was received on this channel because of power problems in the Camac crate.

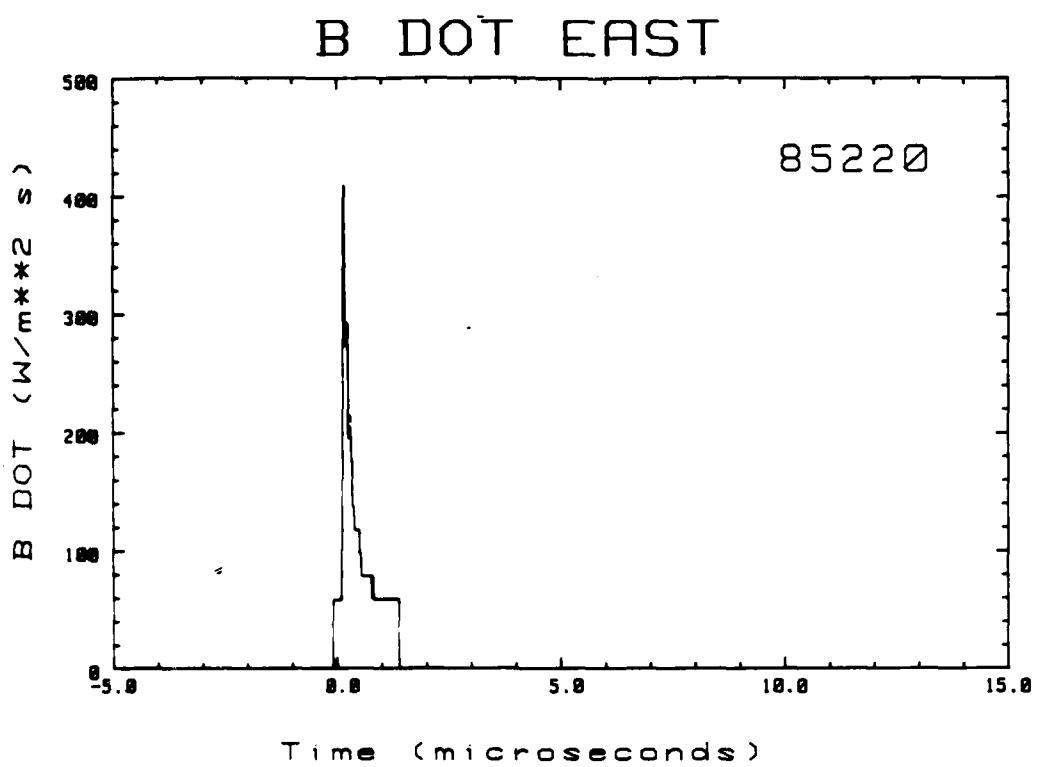


Figure A-7. Values for B-dot East measured in KIVA 1 for D85220.

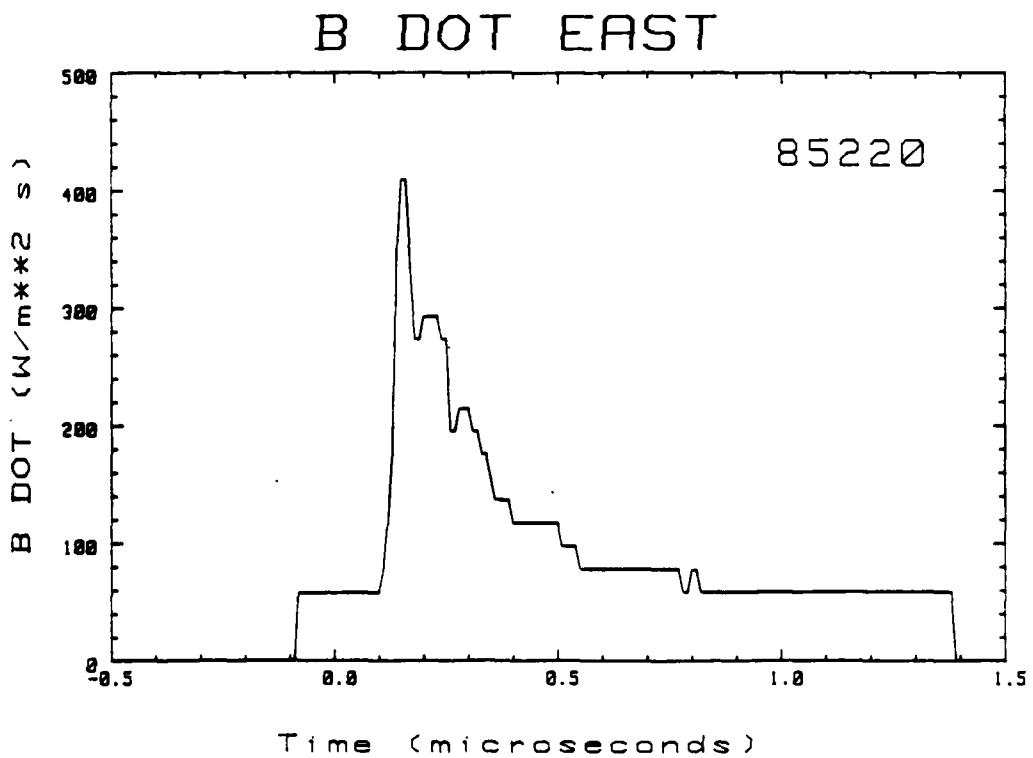


Figure A-8. Expanded view showing initial data from Figure A-7.

MAGNETIC INDUCTION

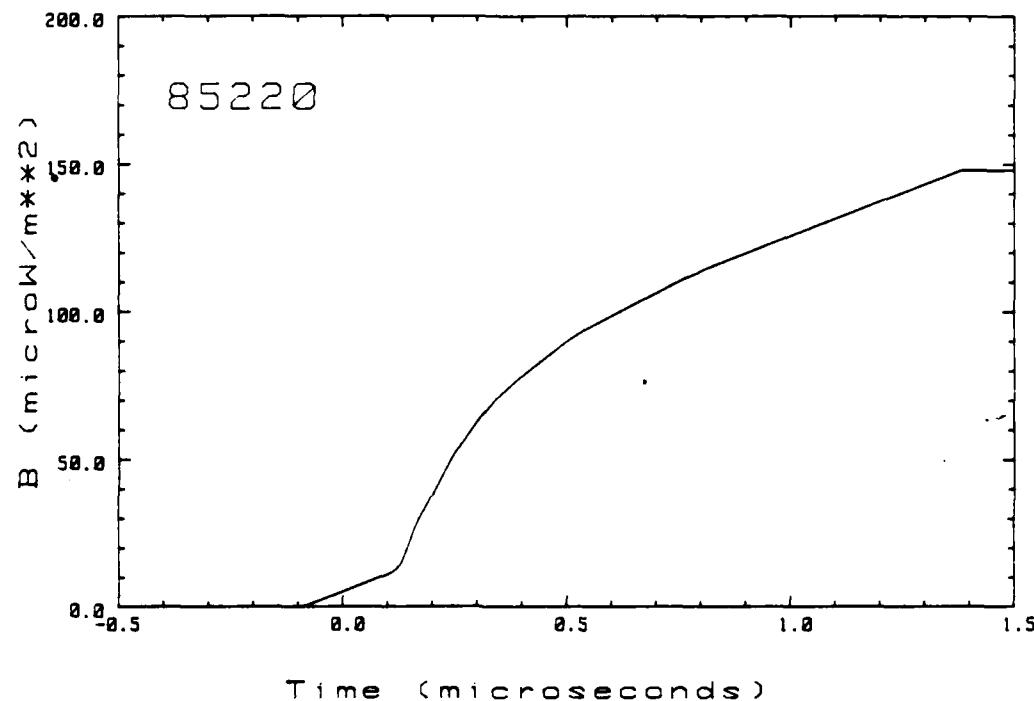


Figure A-9. Values for magnetic induction for D85220 obtained by integration of B-dot East data.

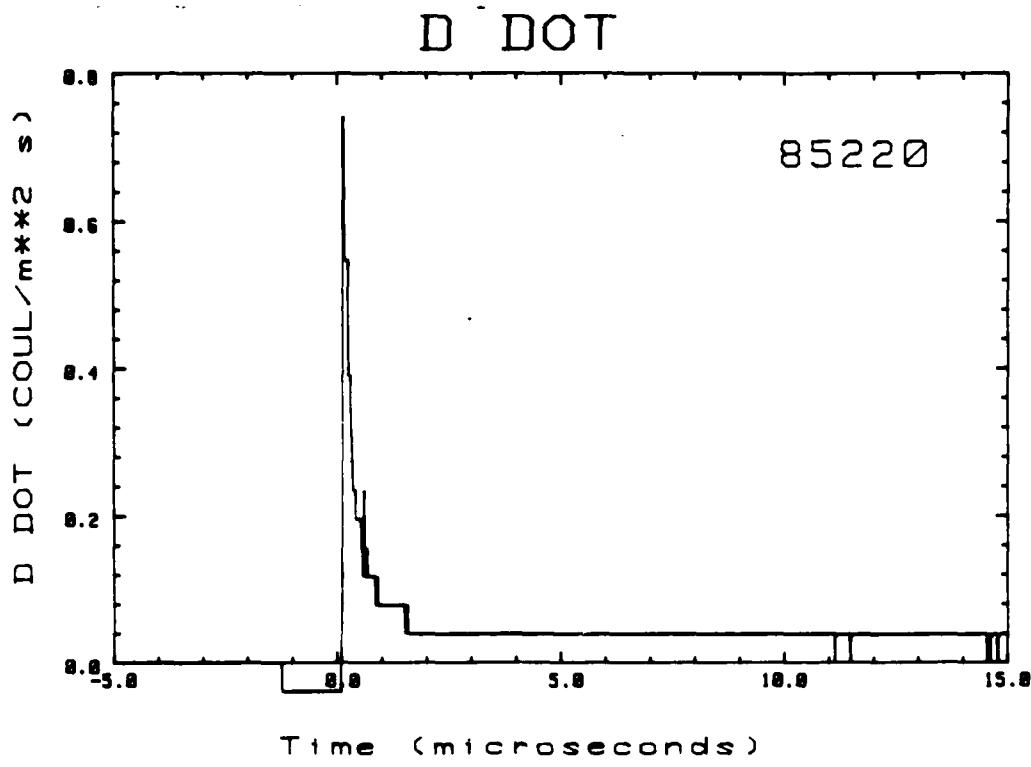


Figure A-10. Values for D-dot measured in KIVA 1 for D85220.

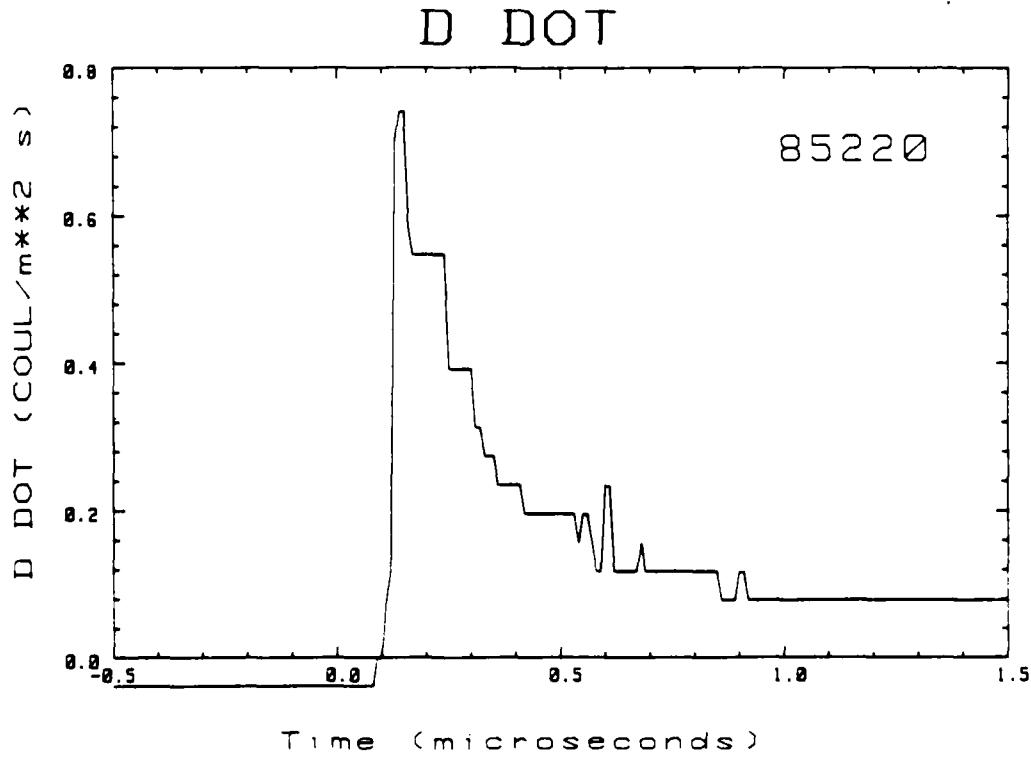


Figure A-11. Expanded view showing initial data from Figure A-10.

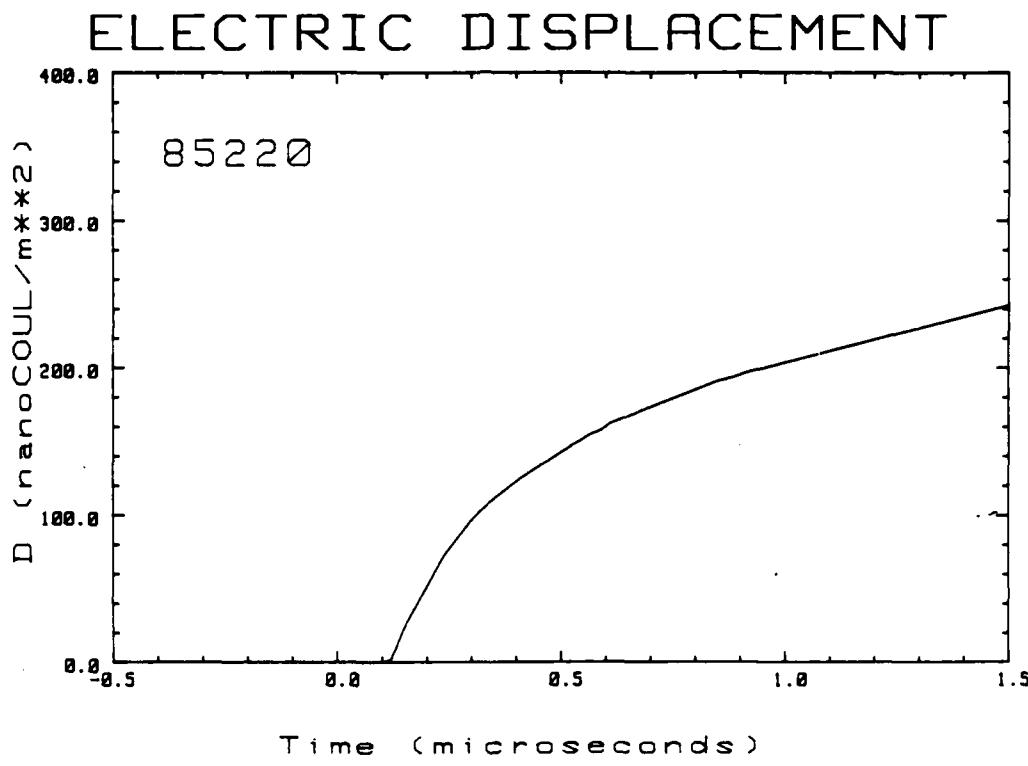


Figure A-12. Values for electric displacement for D85220 obtained by integration of D-dot data.

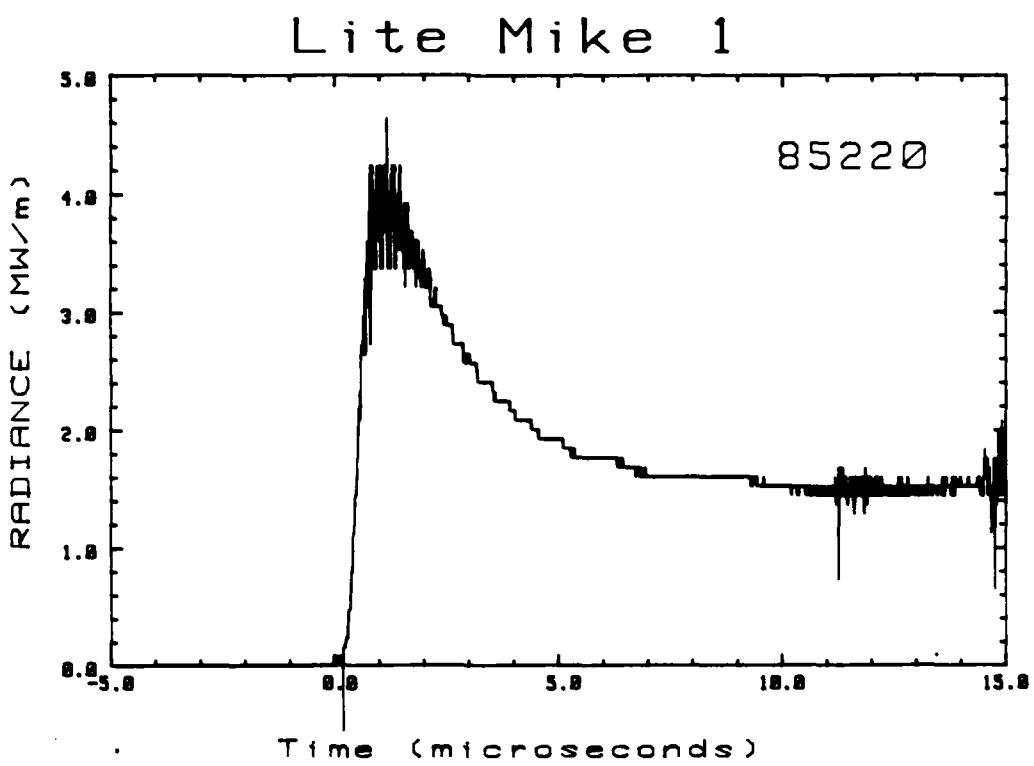


Figure A-13. Values for radiance measured by Lite Mike 1 for D85220.

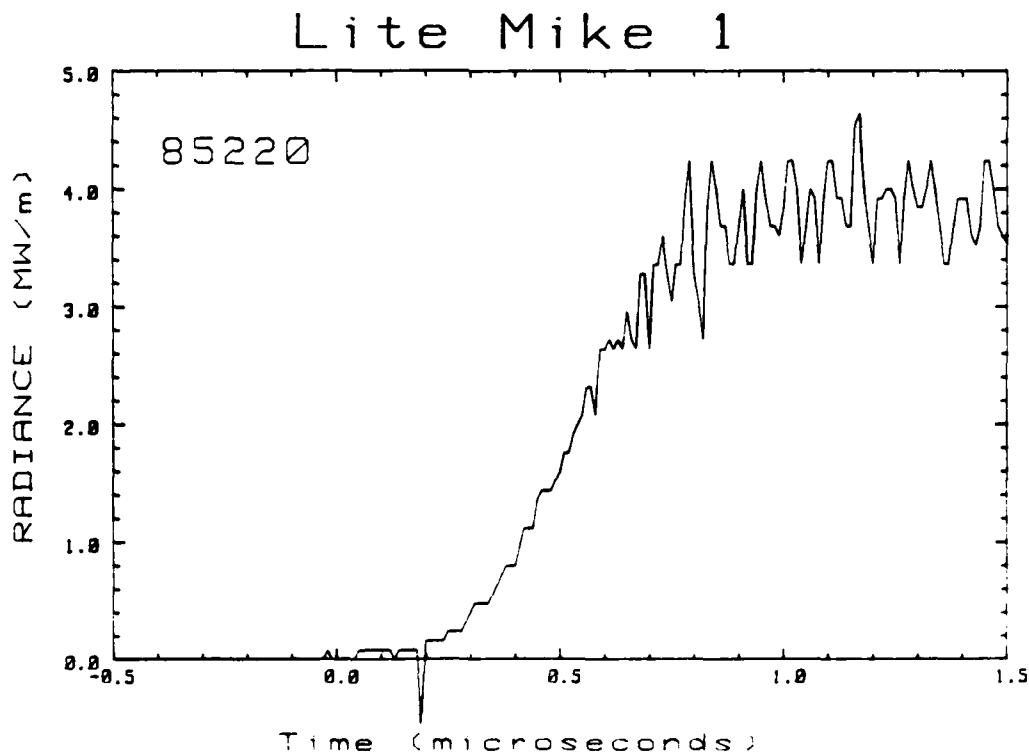


Figure A-14. Expanded view showing initial data from Figure A-13.

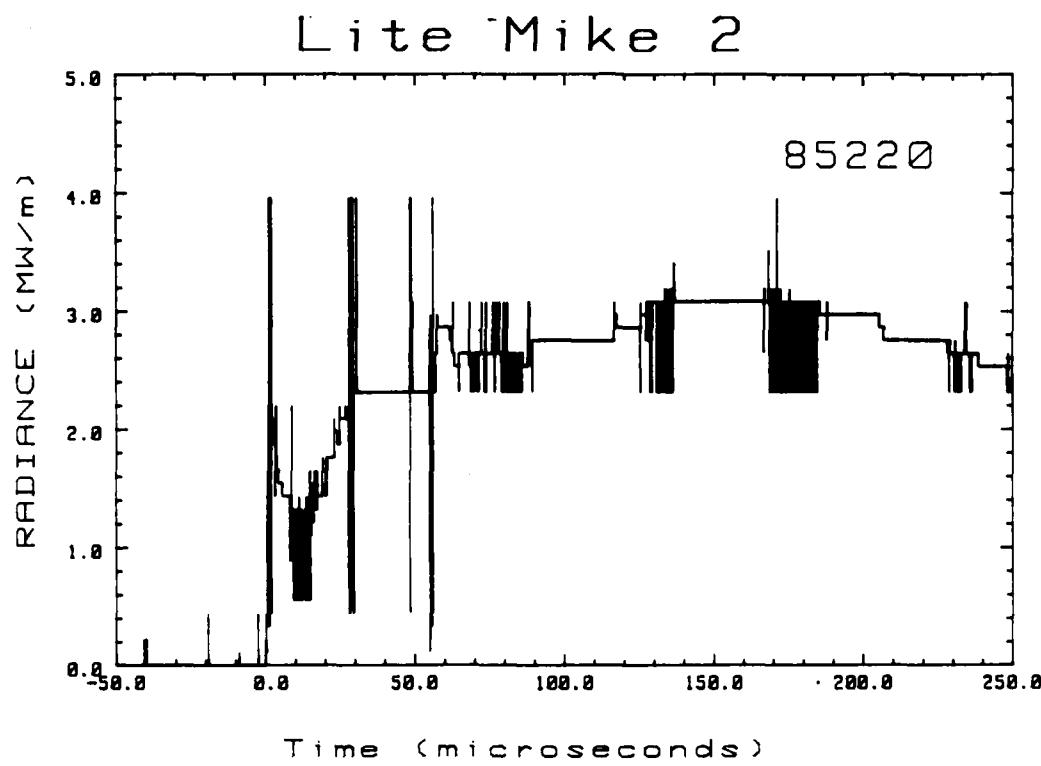


Figure A-15. Values for radiance measured by Lite Mike 2 for D85220.

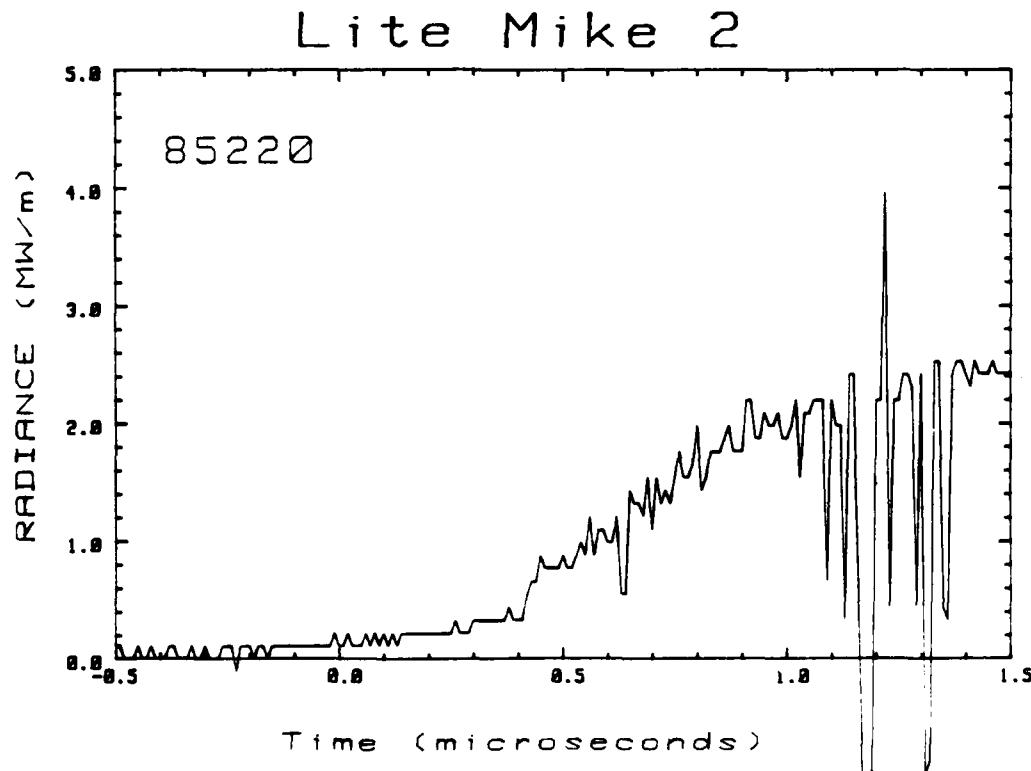


Figure A-16. Expanded view showing initial data from Figure A-15.

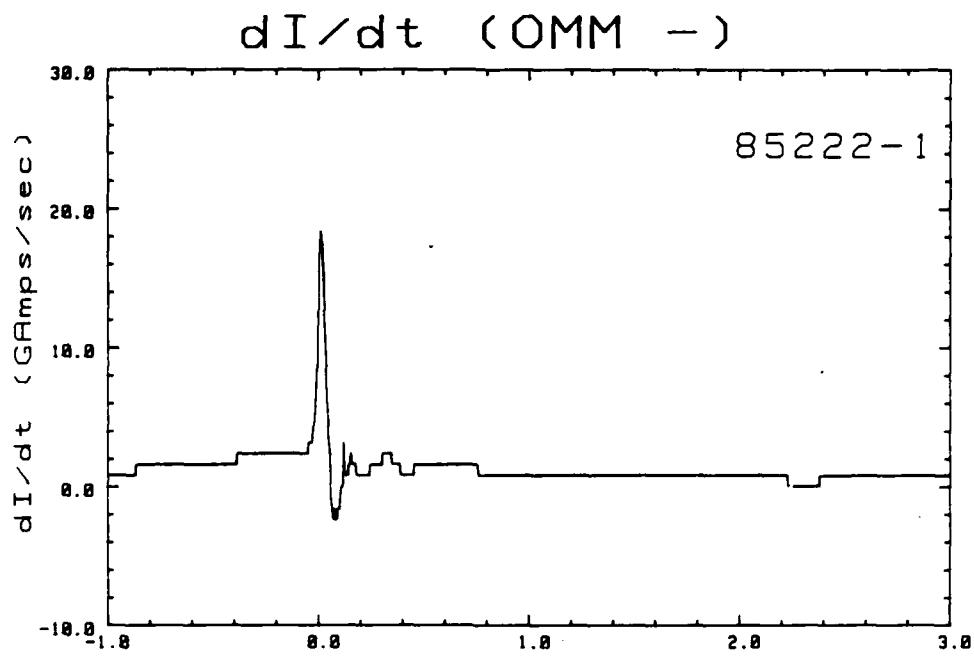


Figure A-17. Values for dI/dt measured with the OMM- sensor channel for first lightning triggered to KIVA 2 on 10 August 1985 (85222-1).

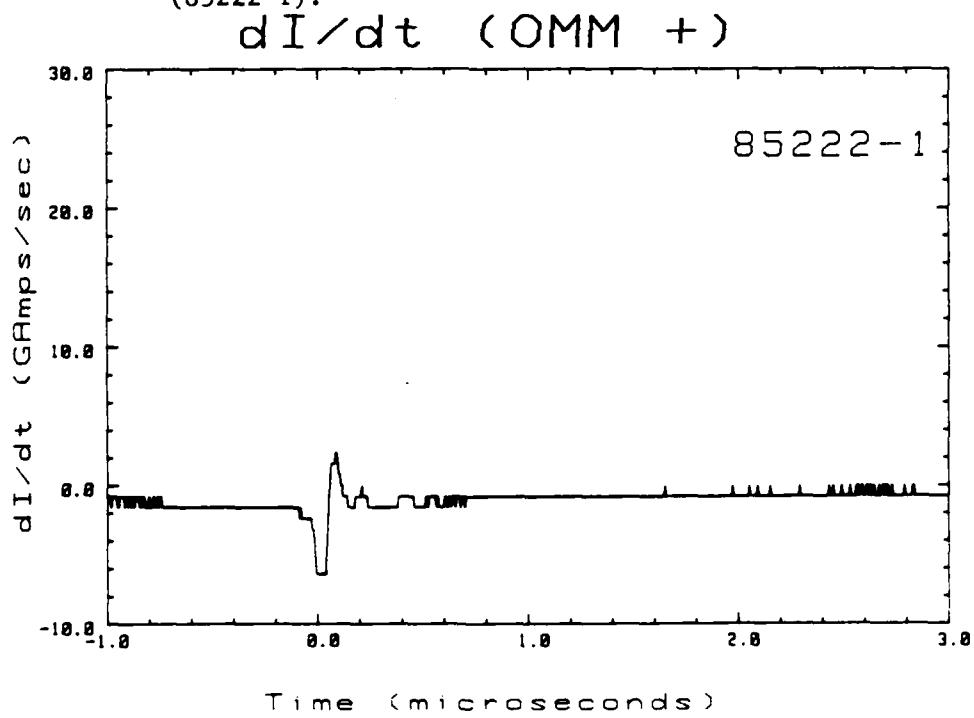


Figure A-18. Values for dI/dt measured with the OMM+ sensor channel for D85222-1.

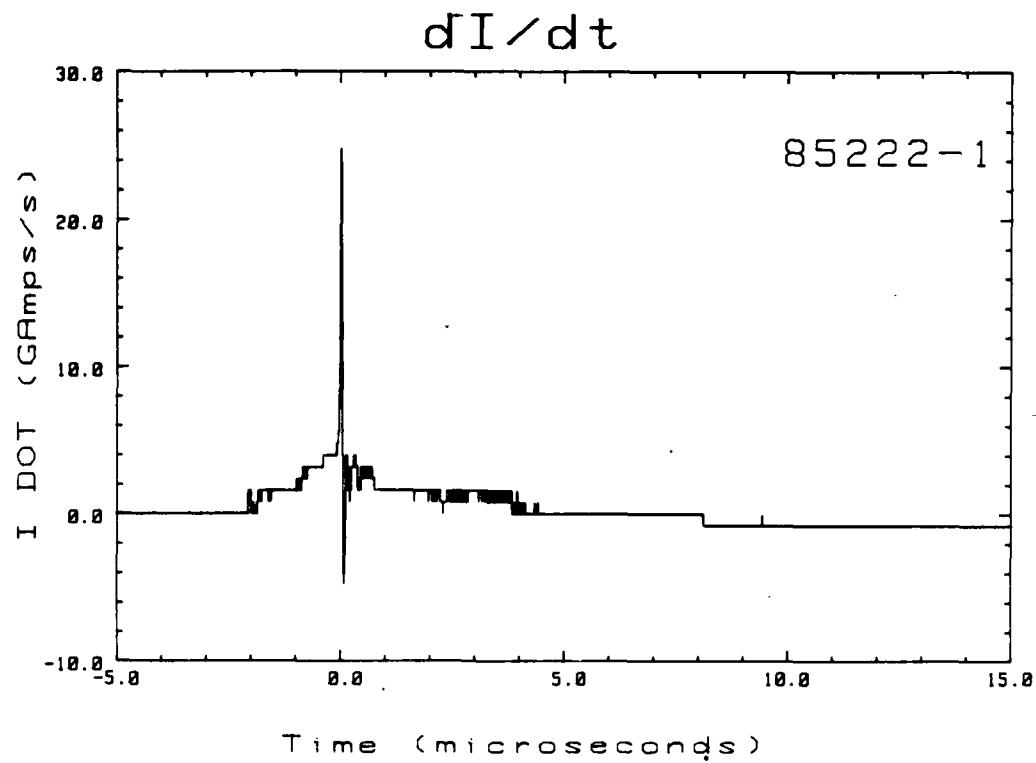


Figure A-19. Values for dI/dt found by summing OMM- and OMM+ channels for D85222-1.

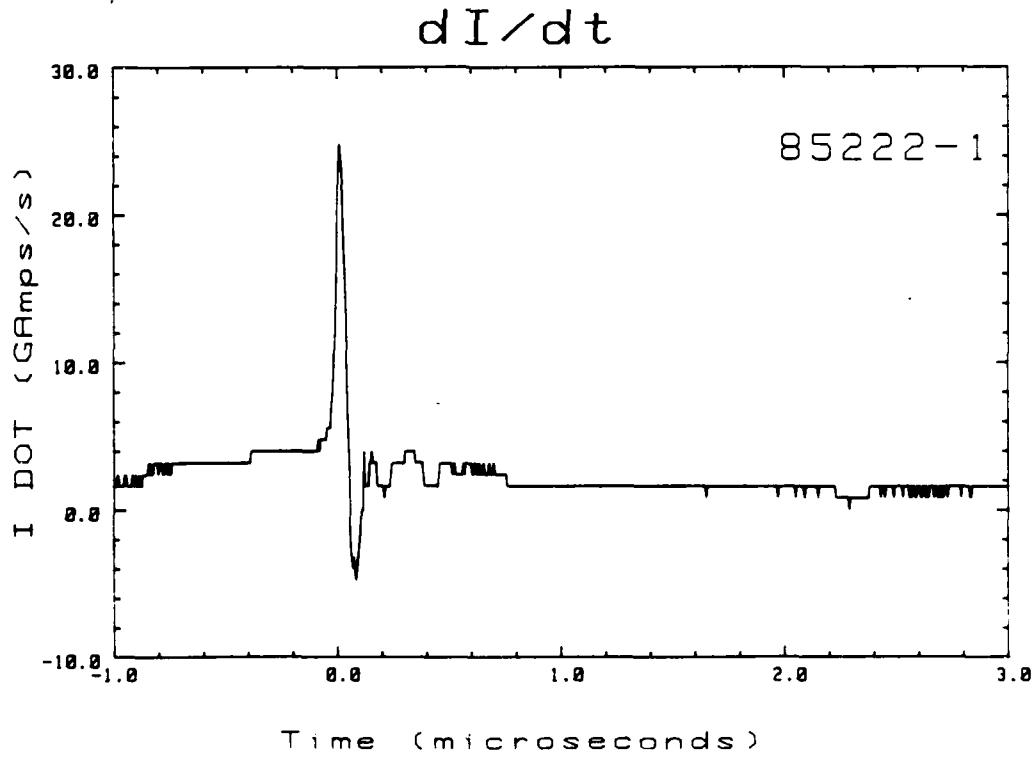


Figure A-20. Expanded view showing initial data from Figure A-19.

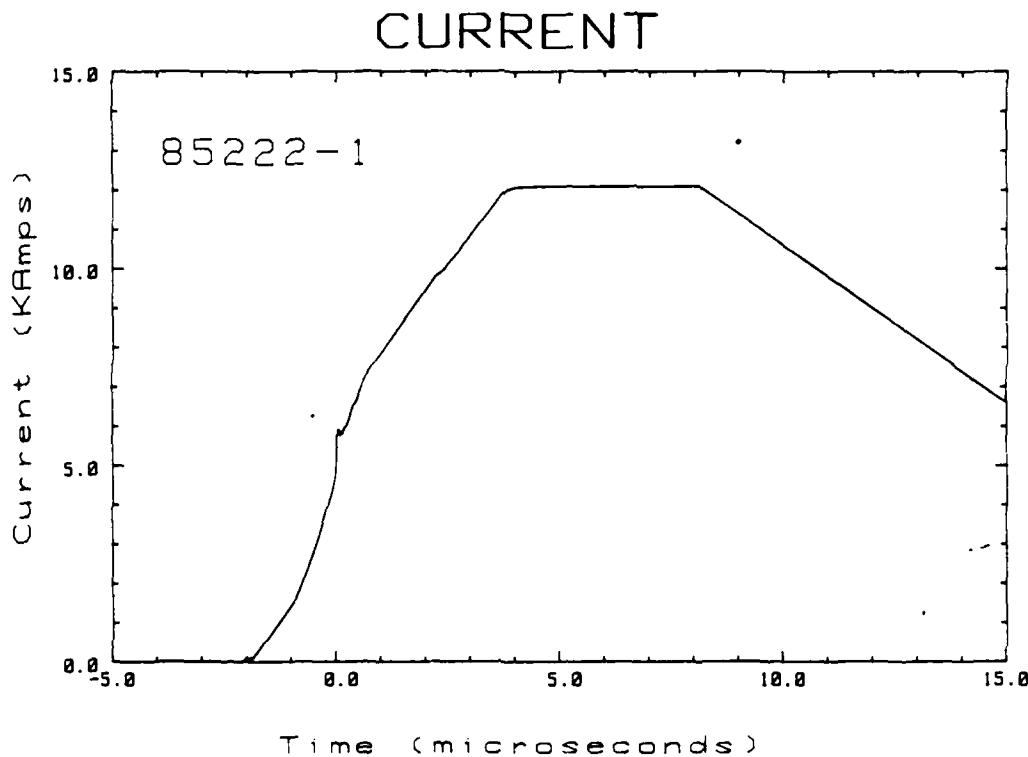


Figure A-21. Values for current found by integration of dI/dt data for D85222-1.

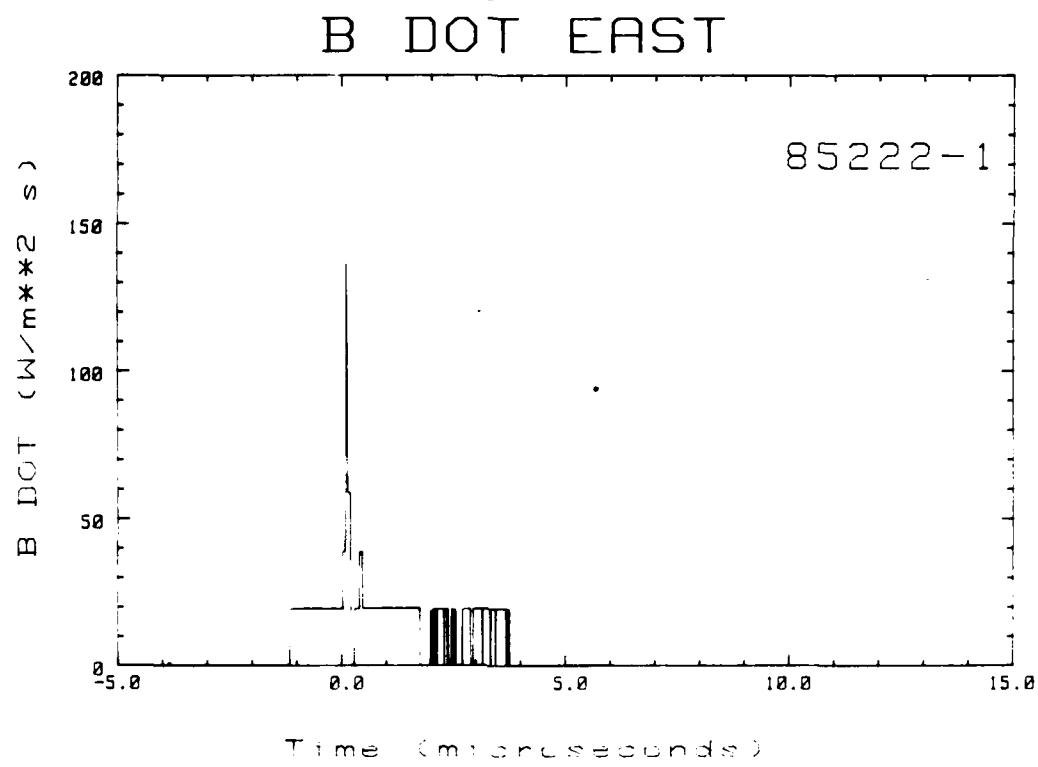


Figure A-22. Values for B-dot East measured in KIVA 1 for D85222-1.

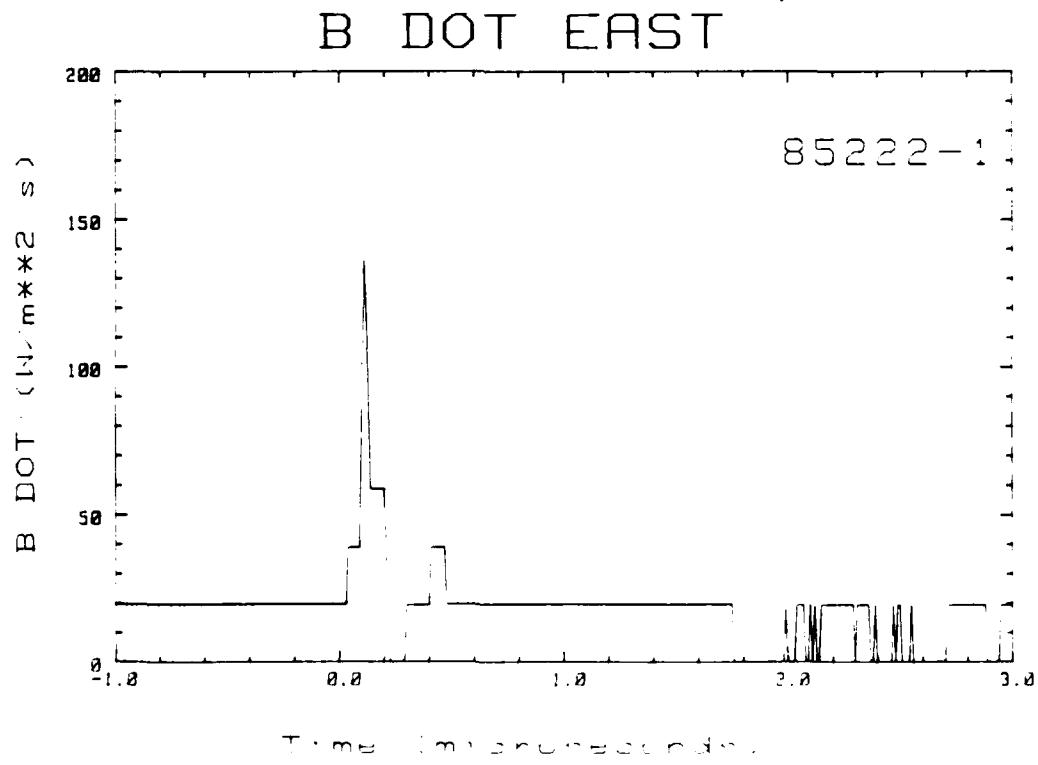


Figure A-23. Expanded view showing initial data from Figure A-22.

MAGNETIC INDUCTION

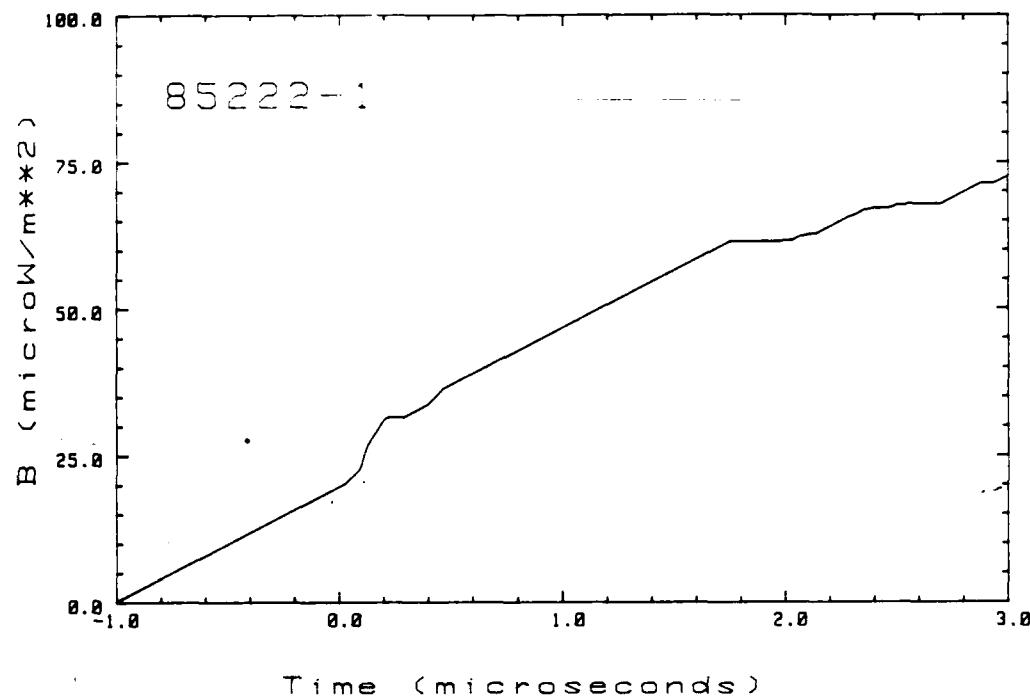


Figure A-24. Values for magnetic induction found by integration of B-dot East data for D85222-1.

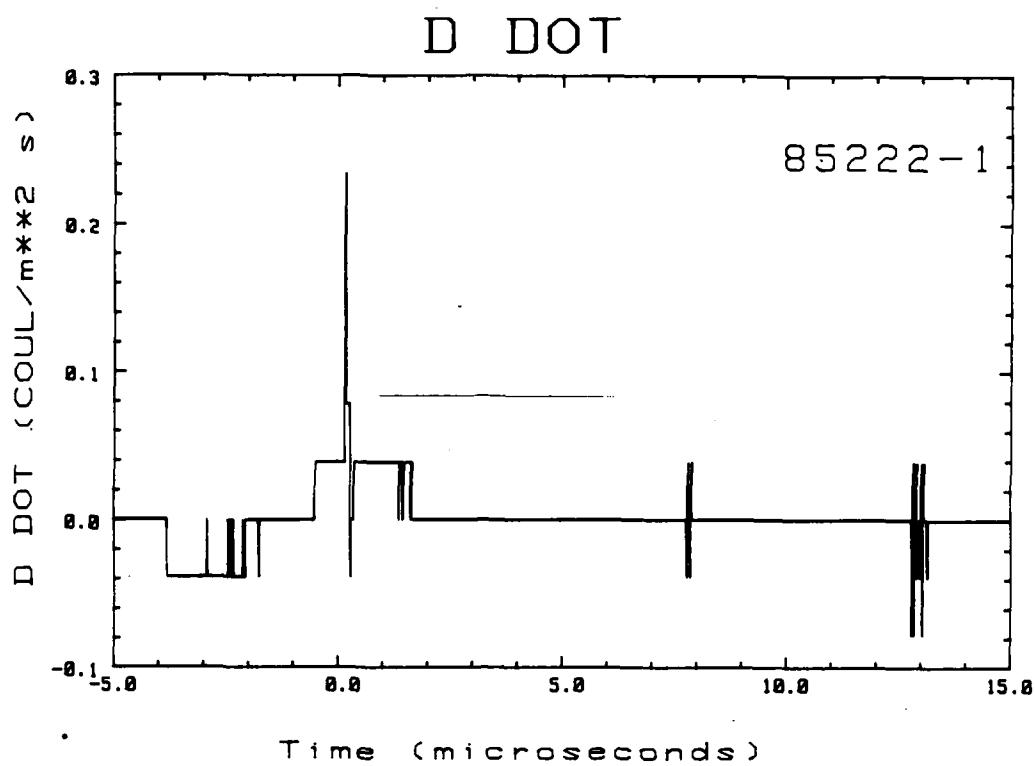


Figure A-25. Values for D-dot measured in KIVA 1 for 85222-1.

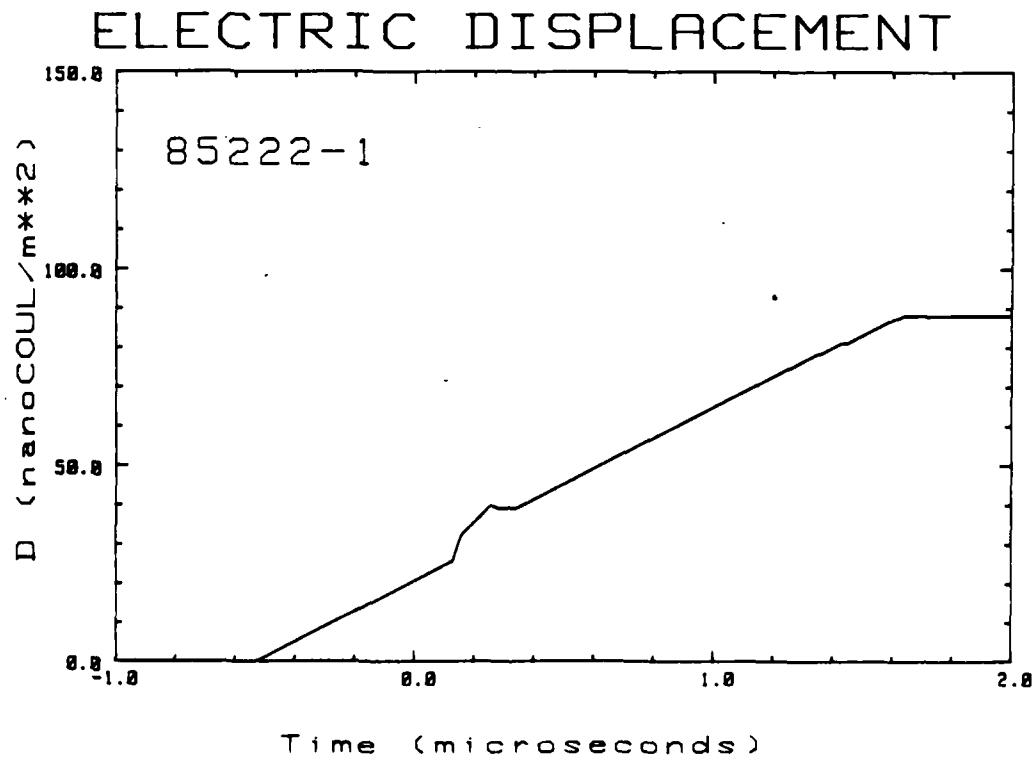


Figure A-26. Values for electric displacement found by integration of D-dot data for D85222-1.

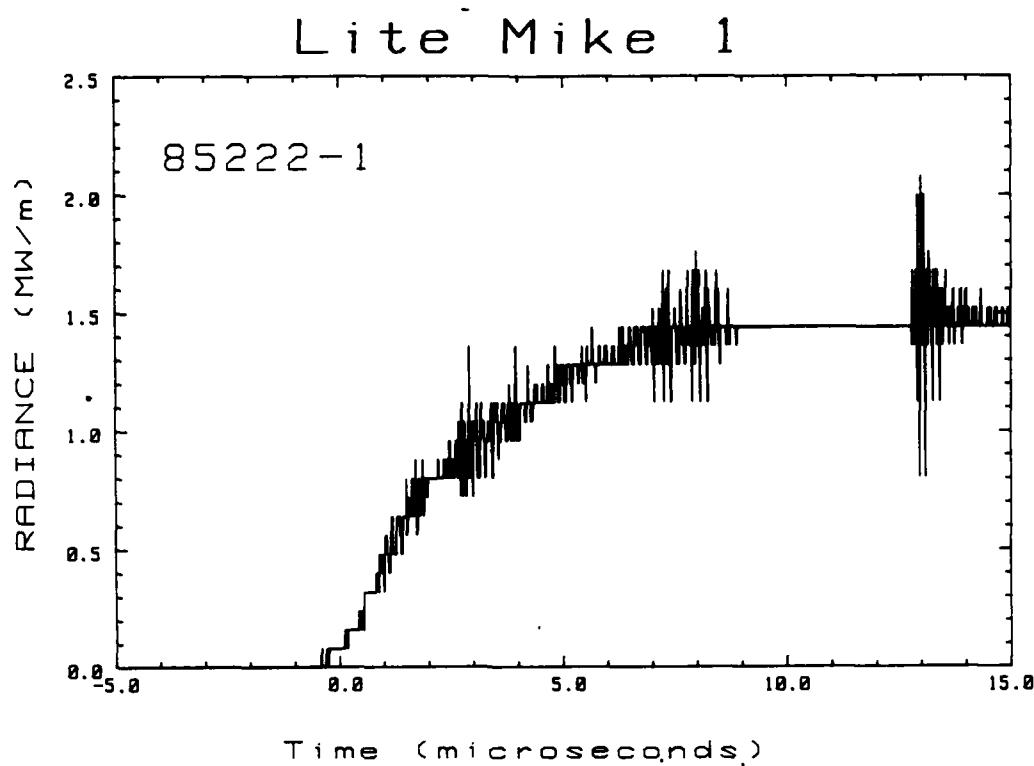


Figure A-27. Values for radiance measured by Lite Mike 1 for D85222-1.

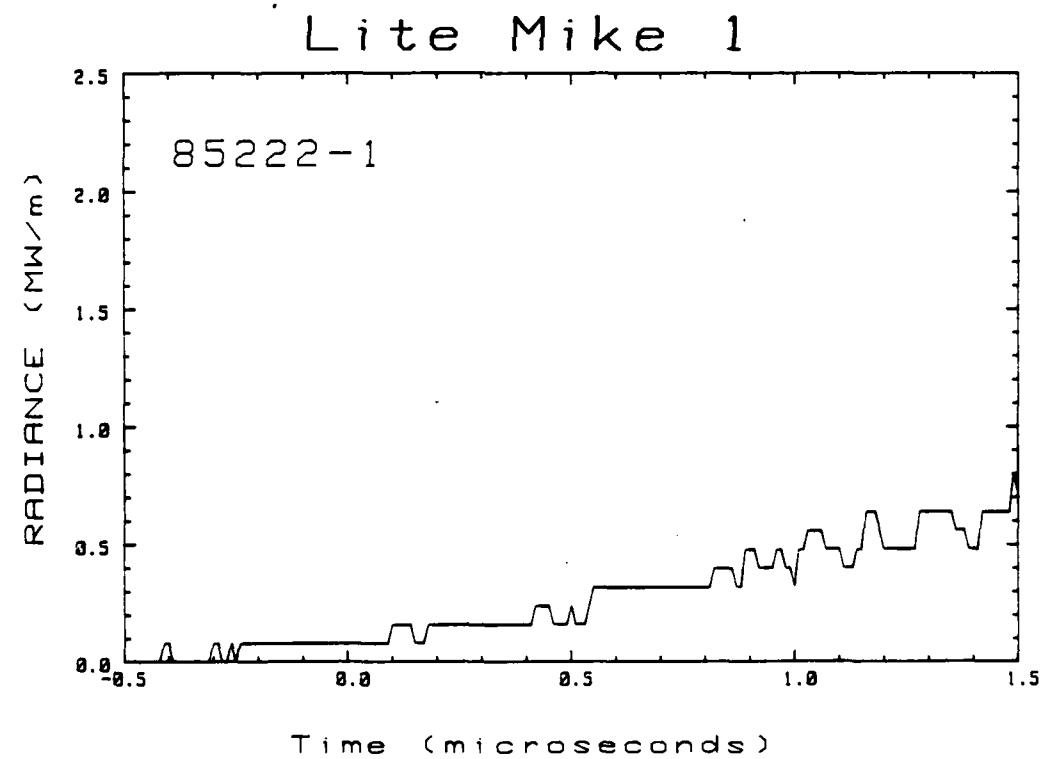


Figure A-28. Expanded view showing initial data from Figure A-27.

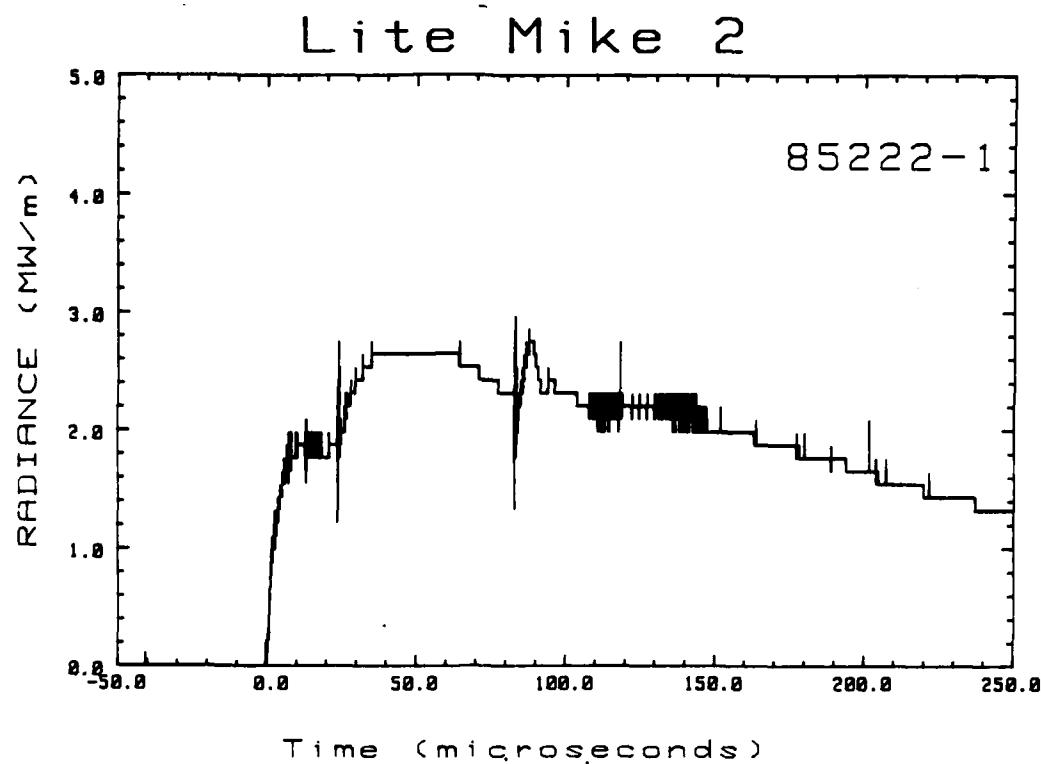


Figure A-29. Values for radiance measured by Lite Mike 2 for D85222-1.

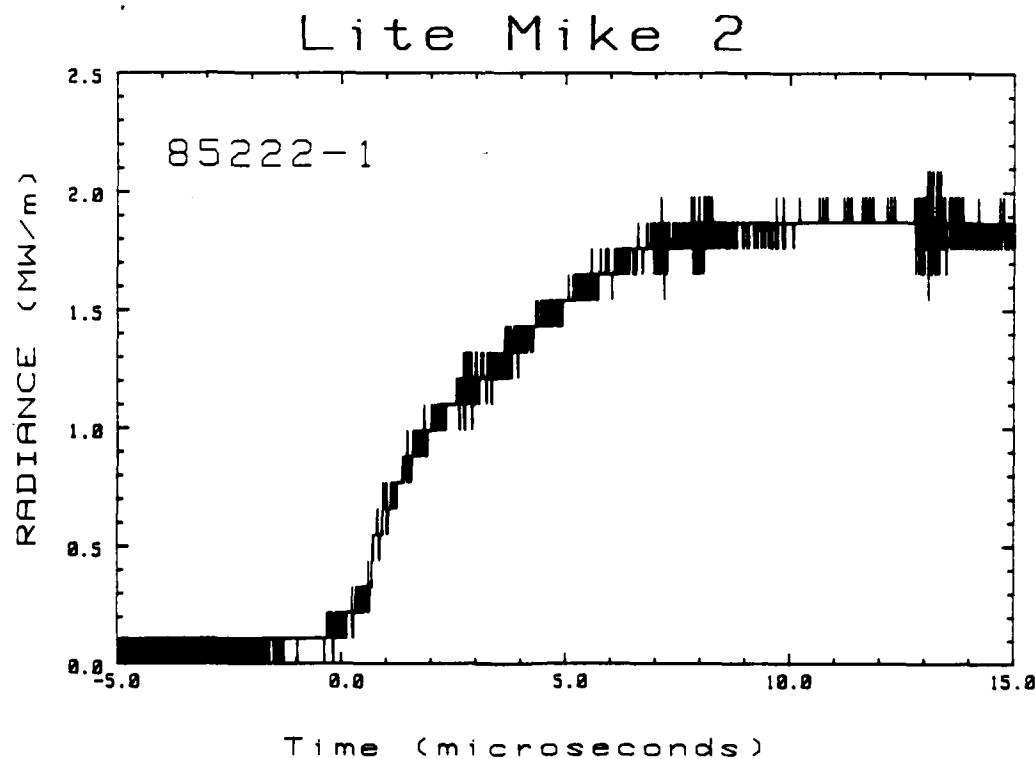


Figure A-30. Expanded view showing initial data from Figure A-29.

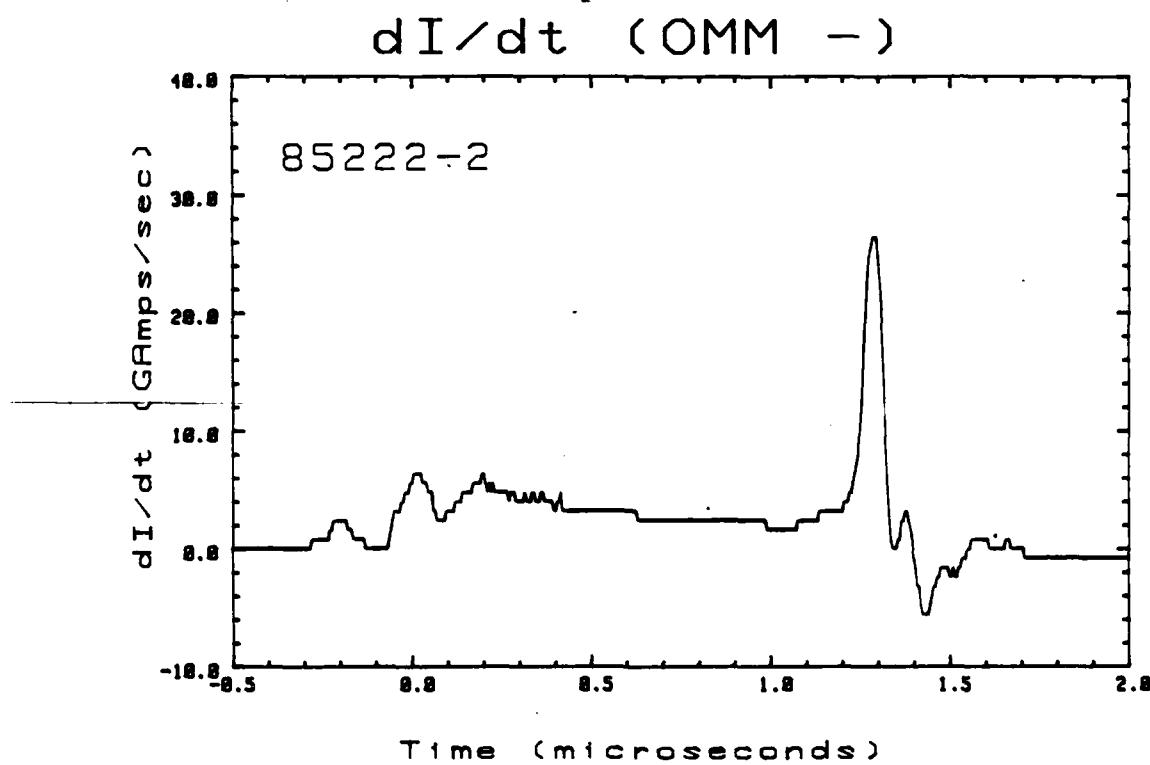


Figure A-31. Values for dI/dt measured by OMM- sensor channel for second lightning triggered to KIVA 2 on 10 August 1985 (85222-2).

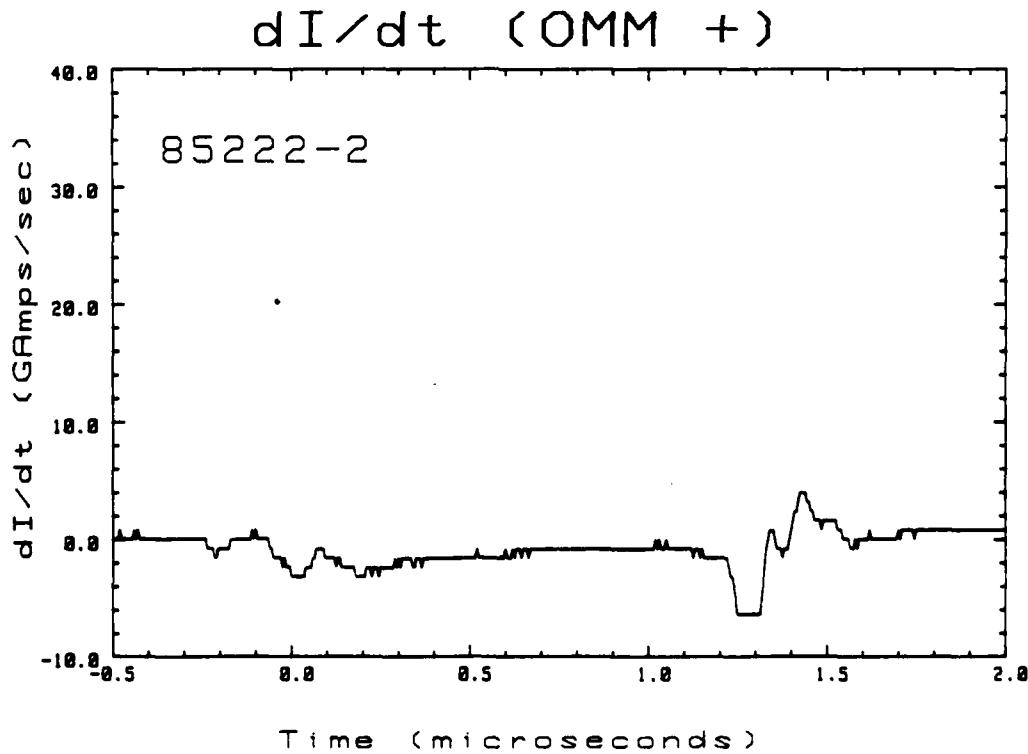


Figure A-32. Values for dI/dt measured by OMM+ sensor channel for D85222-2.

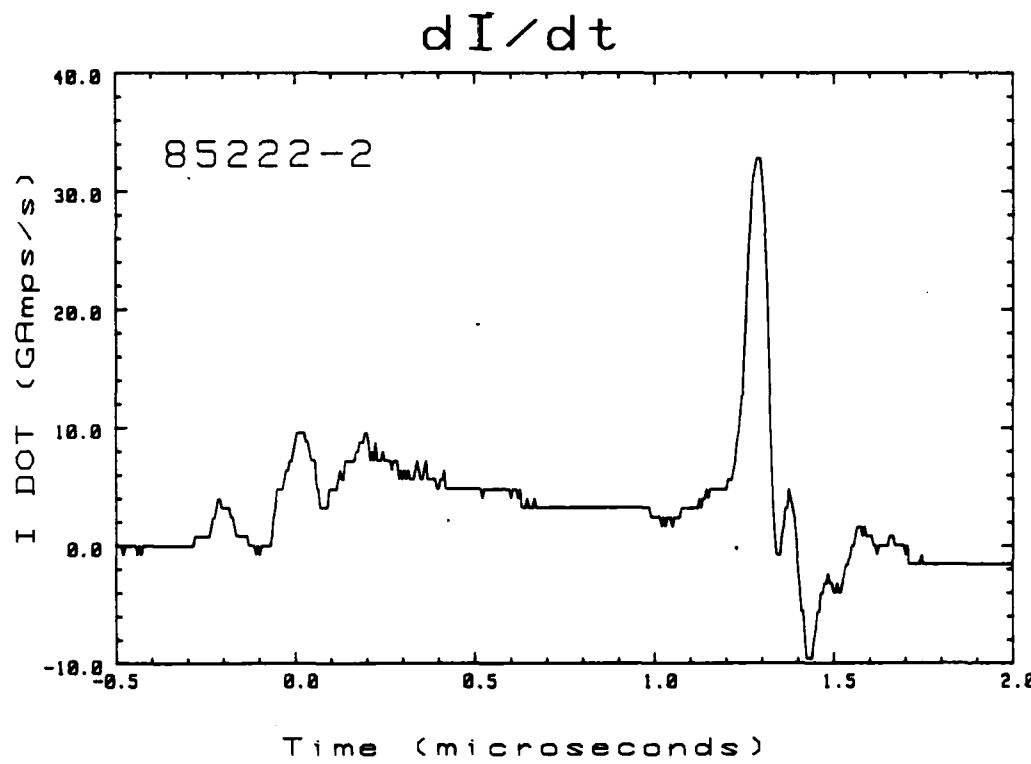


Figure A-33. Values for dI/dt found by summing OMM+ and OMM- channels for D85222-2.

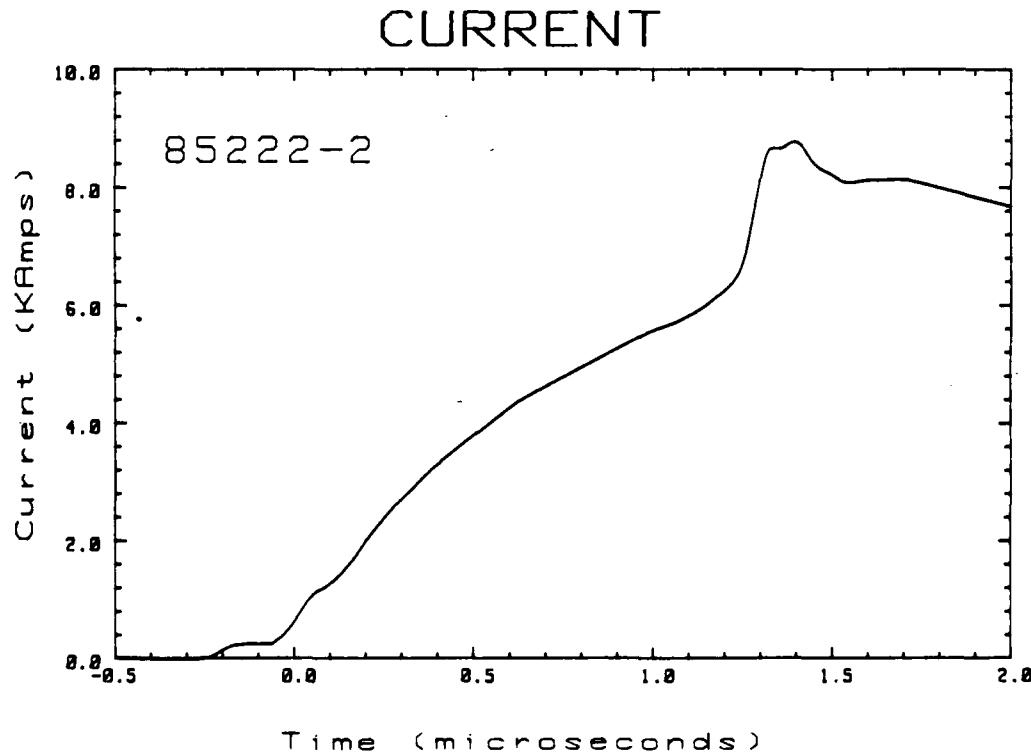


Figure A-34. Values for current found by integration of dI/dt data for D85222-2.

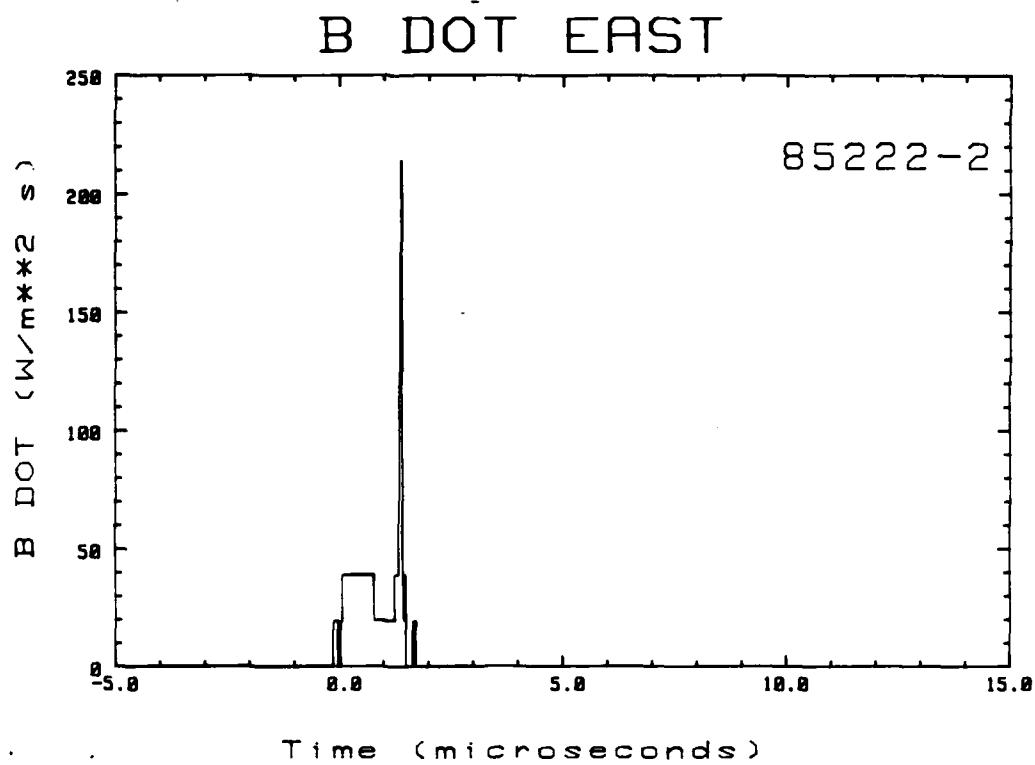


Figure A-35. Values for B-dot East measured in KIVA 1 for D85222-2.

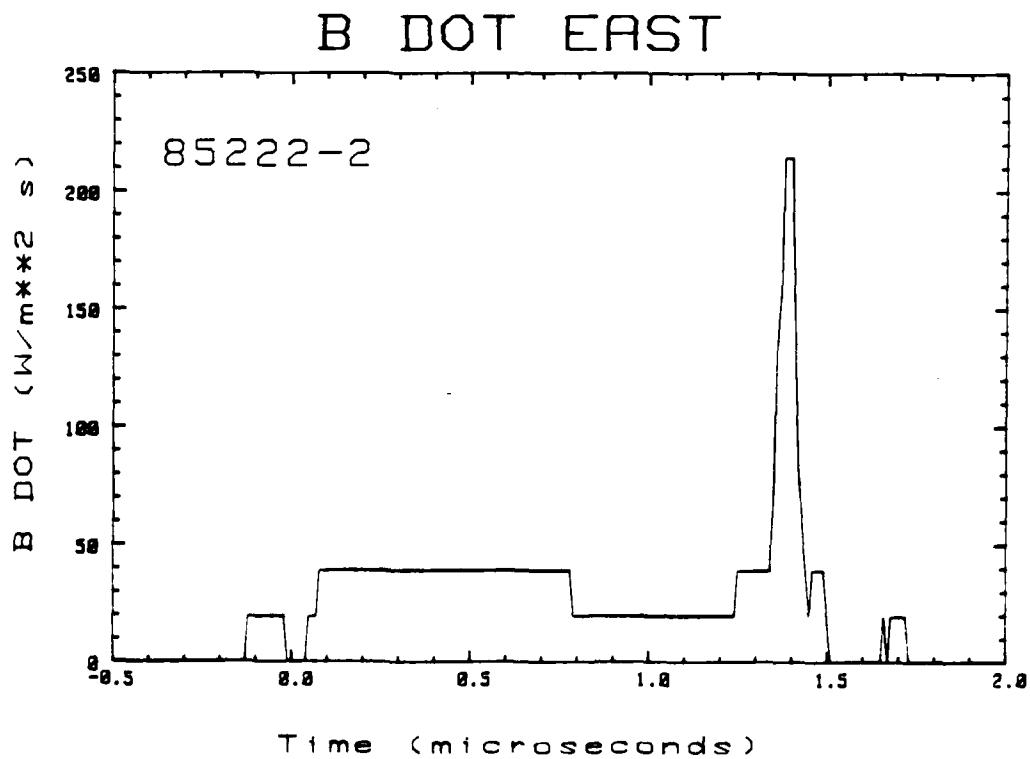


Figure A-36. Expanded view showing initial data from Figure A-35.

MAGNETIC INDUCTION

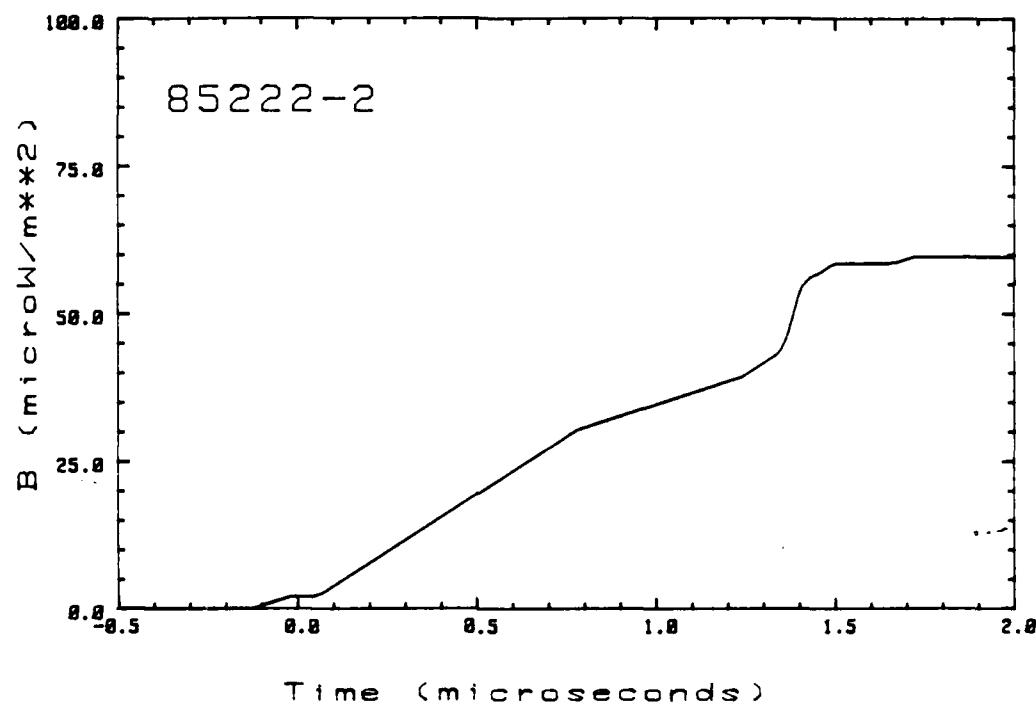


Figure A-37. Values for magnetic induction found by integration of B-dot East data for D85222-2.

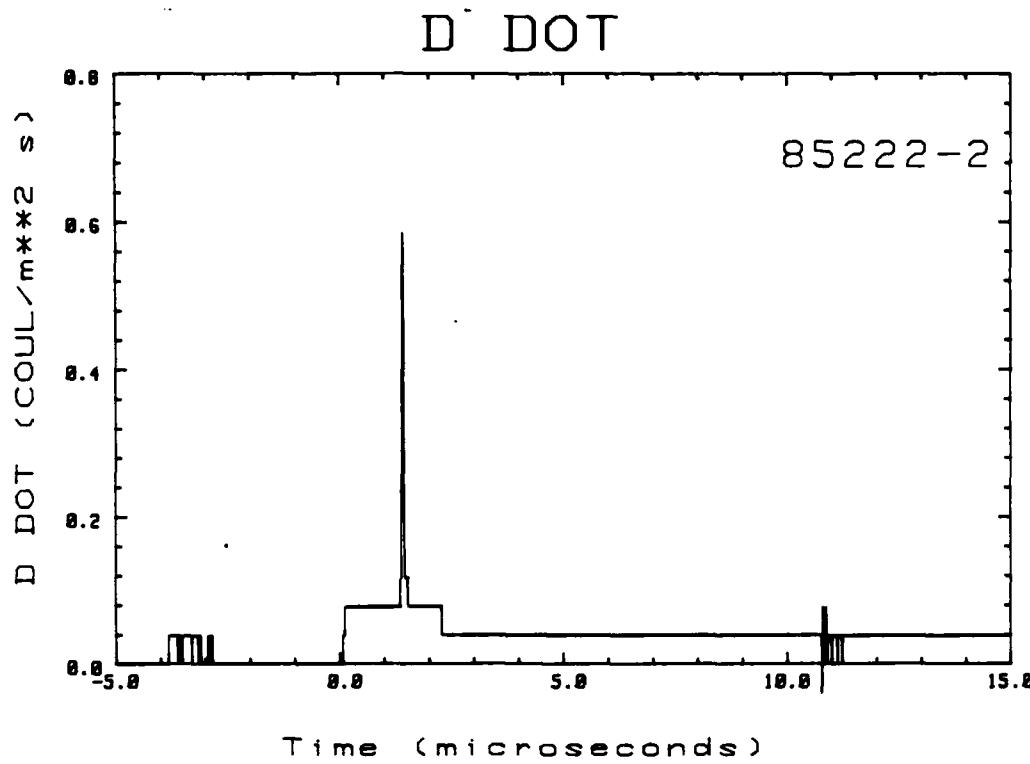


Figure A-38. Values for D-dot measured in KIVA 1 for D85222-2.

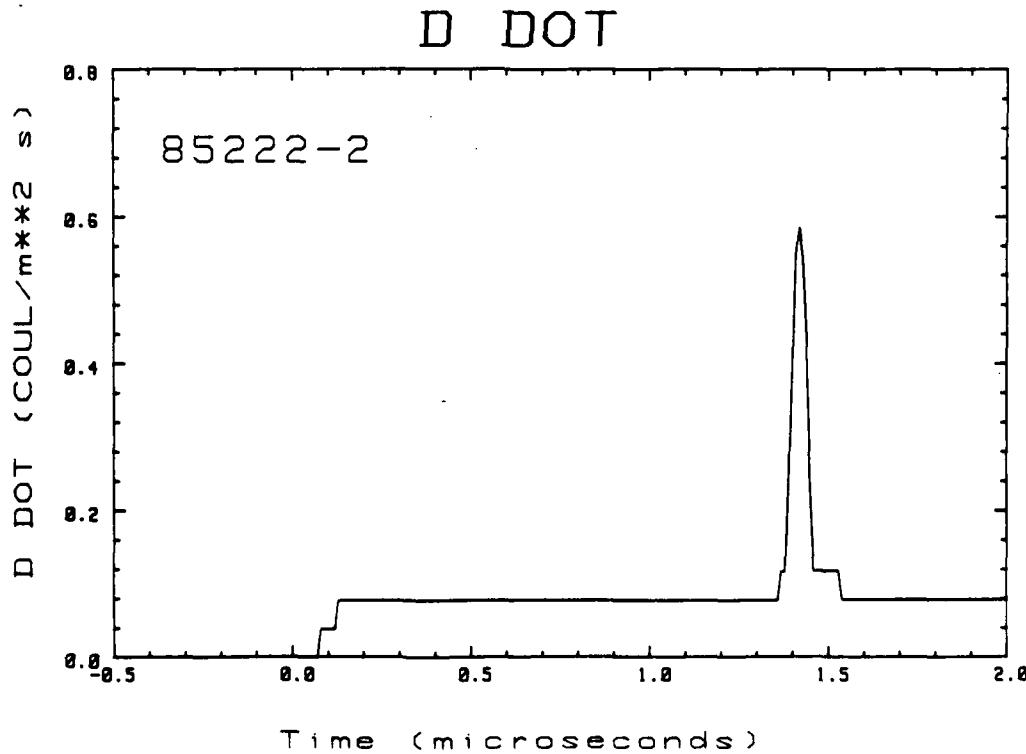


Figure A-39. Expanded view showing initial data from Figure A-38.

ELECTRIC DISPLACEMENT

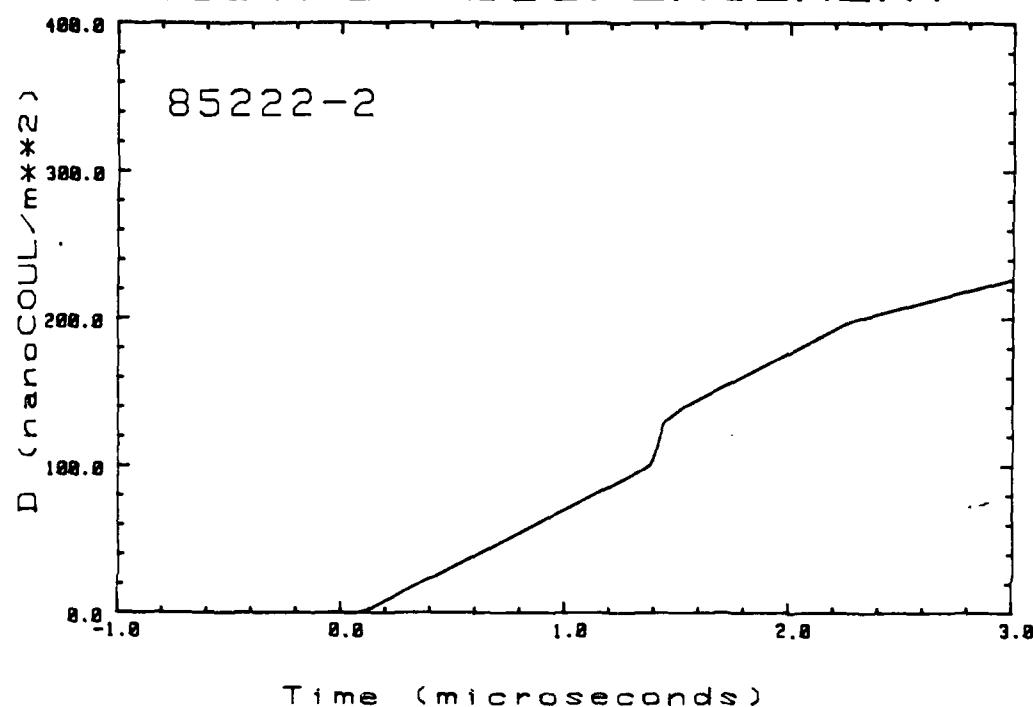


Figure A-40. Values for electric displacement found by integration of D-dot data for D85222-2.

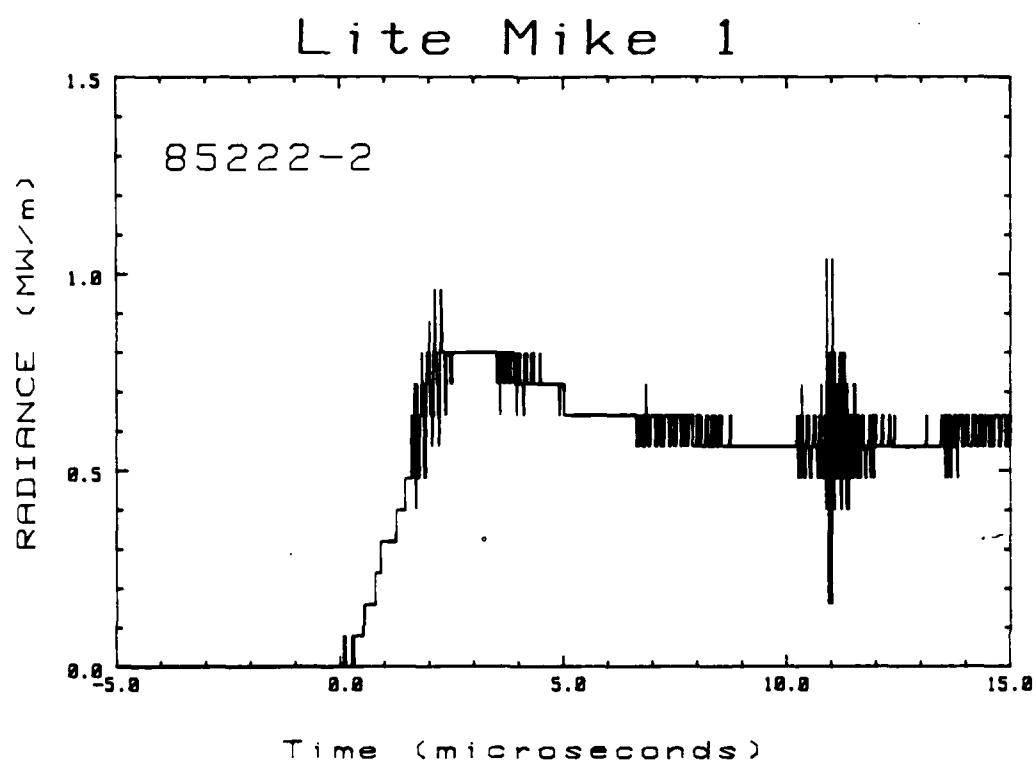


Figure A-41. Values for radiance measured by Lite Mike 1 for D85222-2.

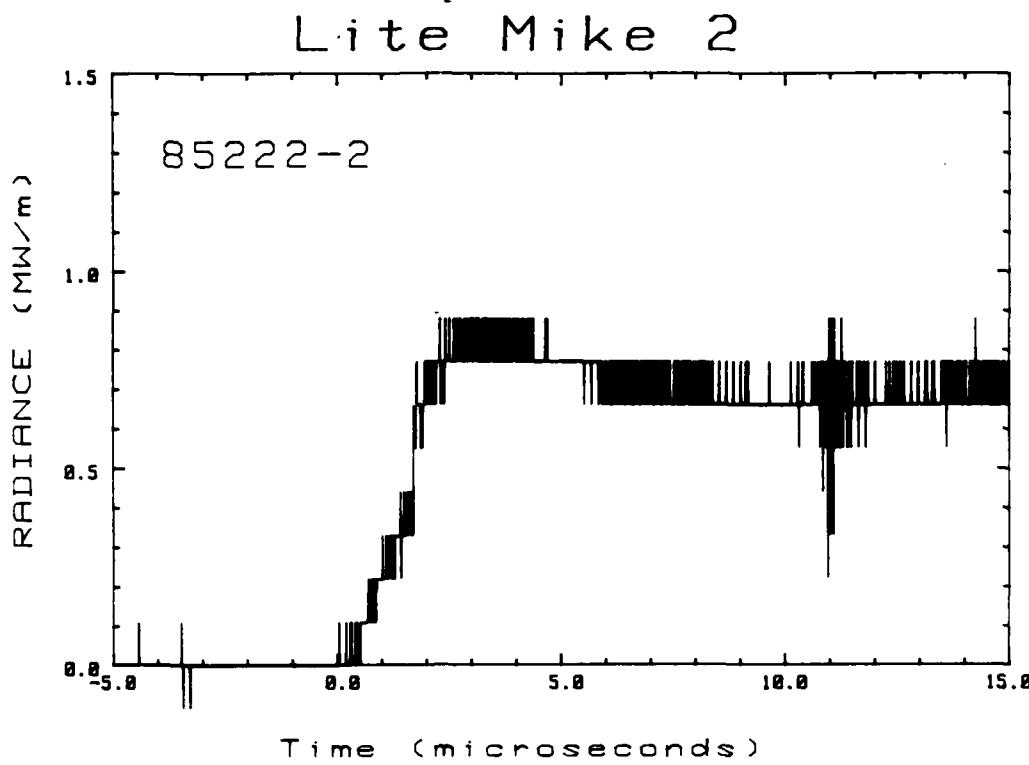


Figure A-42. Values for radiance measured by Lite Mike 2 for D85222-2.

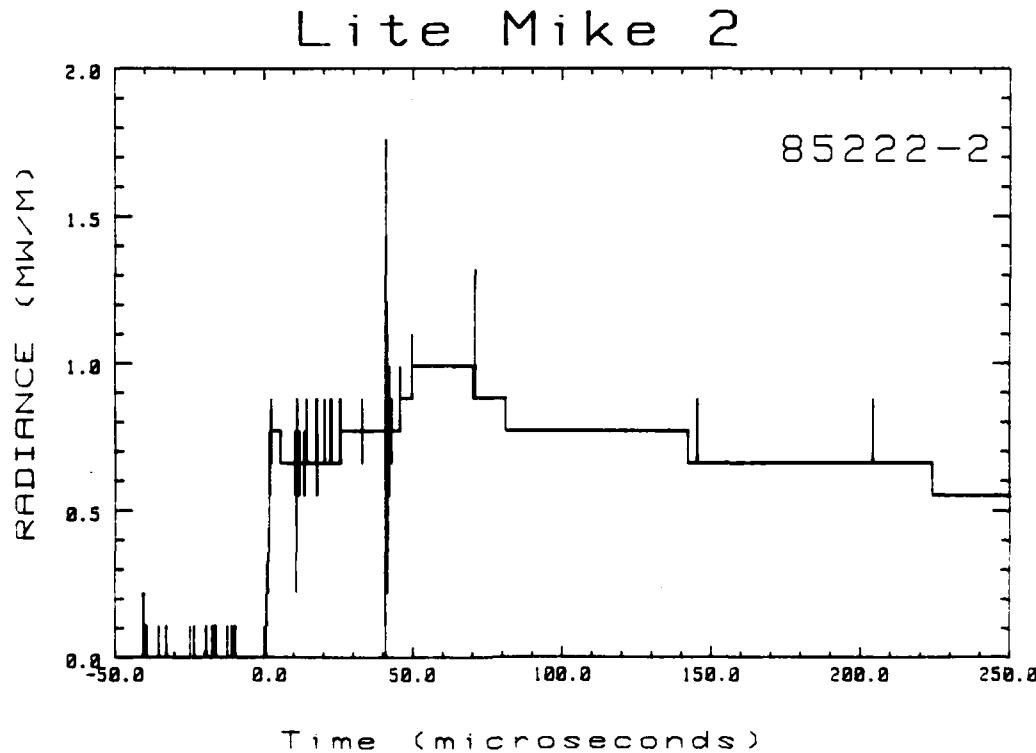


Figure A-43. Expanded view showing initial data from Figure A-42.

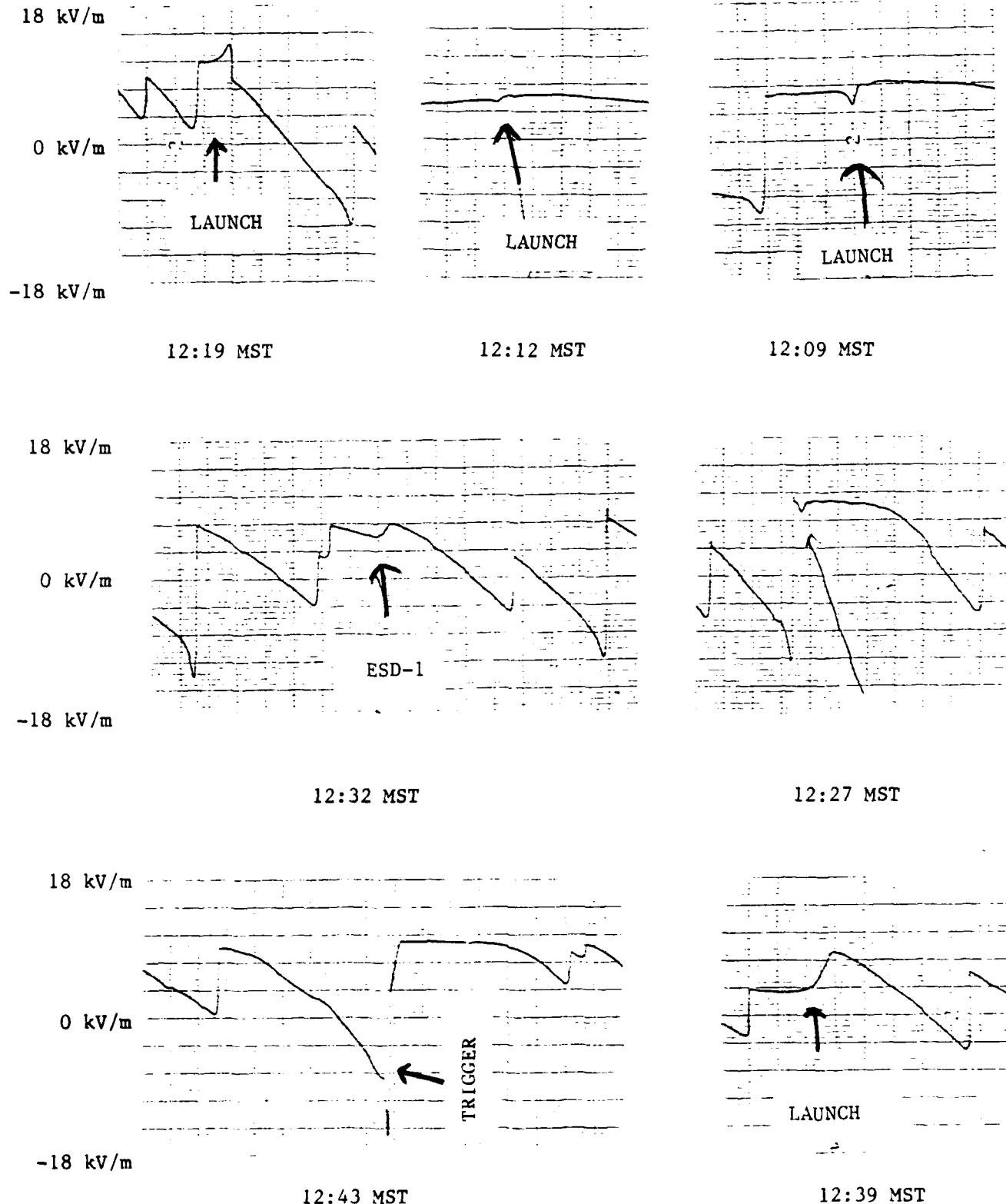


Figure A-44. Electric field record showing excursions in the electric field produced by rocket launches during the storm of 10 August 1985 (85222). Time increases from right to left. One small vertical division is a field strength of 713 V/m; one horizontal division is five seconds.

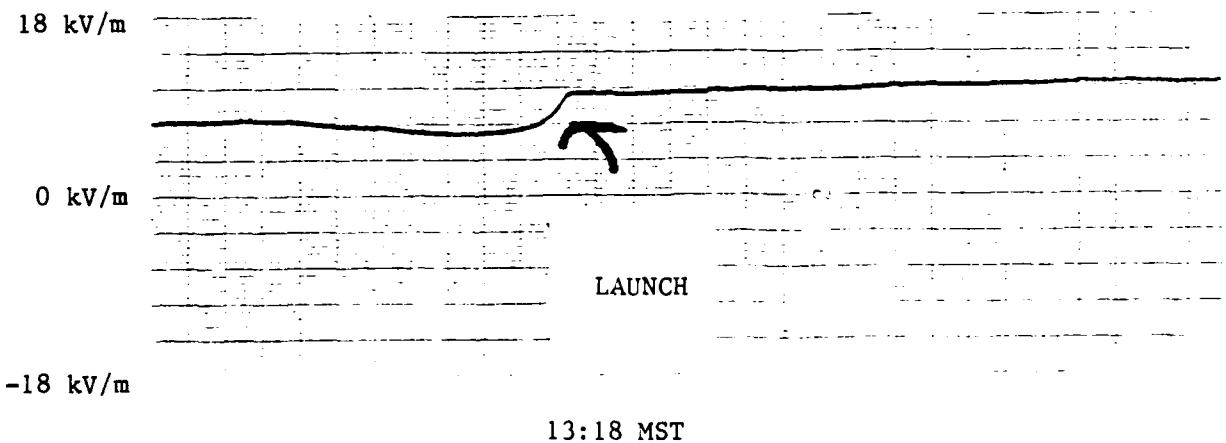
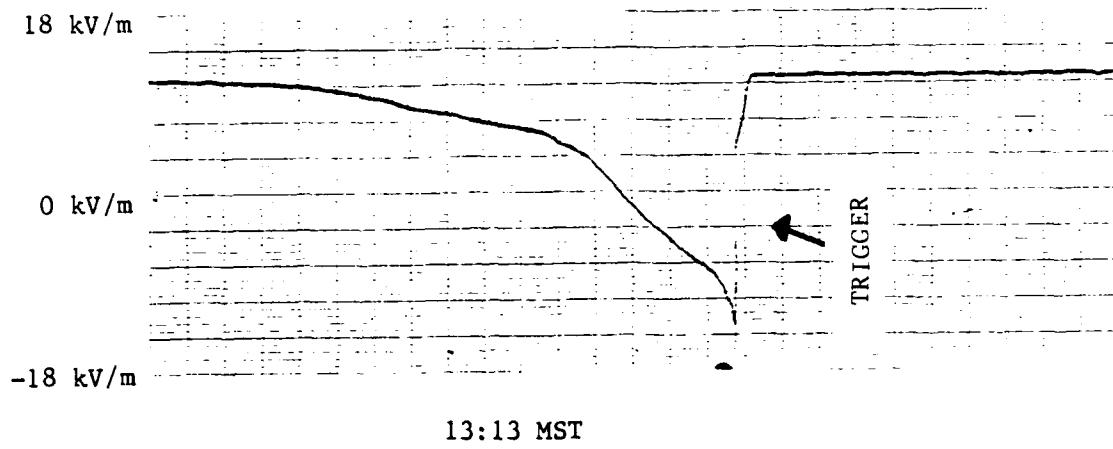
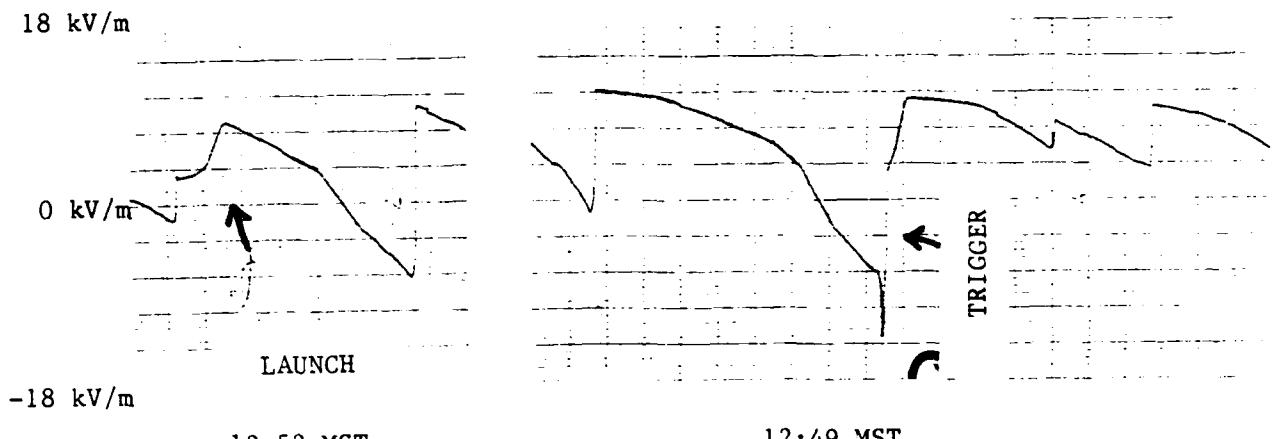


Figure A-44. (Concluded.)

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